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Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes:

Background Information Document

Final Report

Prepared for

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I. Executive Summary

A. Background

In May of 1993, the Environmental Protection Agency (EPA) introduced a draft Waste Minimization and Combustion Strategy designed to encourage waste minimization and to ensure that combustion of hazardous waste does not pose a threat to human health and the environment. One of the key objectives of the strategy is to assess the risk to human health and the environment from the burning of hazardous wastes and to determine whether additional or more stringent emissions standards are needed. Three categories of sources that burn hazardous waste are addressed here and in the proposed rule. They are

- Incinerators, both commercial and on-site
- Cement kilns
- Lightweight aggregate kilns.

The standards are being proposed under joint authority of the Clean Air Act and the Resource Conservation and Recovery Act.

In coordination with other EPA Offices, the Technical Assessment Branch of the Office of Solid Waste has developed a multipathway analysis to evaluate the health and ecological risks associated with hazardous waste combustion and the reduction in risk achieved by the proposed regulatory options. The chosen approach--multipathway risk analysis at sample facilities--builds on recent EPA efforts to refine assessment of indirect exposures to hazardous pollutants and better characterize the risk posed by dioxin-like compounds. The objective of the risk assessment is to provide the best estimates possible of the risks to human health and the environment in accordance with EPA's risk characterization guidance (U.S. EPA, 1995b and d) and using the most current exposure methodologies available.[1]

B. Methodology

1. General Method

This multiple pathway analysis focuses on the risks to human health resulting from direct and indirect exposures to emissions from facilities that burn hazardous wastes. The analysis is implemented by defining 12 exposure scenarios for dioxins and metals and calculating risk estimates. The scenarios include farmers, fishers, and residents--both adults and children. Multiple scenarios were used to assess the different levels of risk expected for the general

[1] The objective was not to perform a screening level analysis, which typically involves the use of simplifying and often conservative assumptions.

population and special subpopulations. The methodology used in the risk analysis follows that outlined in the *Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions* (U.S. EPA, 1990b) and its Addendum (U.S. EPA, 1993a). The recent Dioxin Reassessment (U.S. EPA, 1994b and c) provided a source of physical and chemical properties and additional exposure methodology equations used in this analysis.

The risks are quantified using case studies of 11 hazardous-waste-burning facilities and their site-specific land uses and environmental settings. The facilities selected for the case studies were

- Four hazardous waste incinerators
- Five cement kilns that burn hazardous wastes
- Two lightweight aggregate kilns that burn hazardous wastes.

2. Pollutants Analyzed

The pollutants analyzed were congeners of dioxins and furans, selected metals, and hydrogen chloride. The 17 dioxin and furan congeners selected were those for which 2,3,7,8-tetrachlorodibenzo(*p*)dioxin toxicity equivalence factors (TCDD-TEFs) are available. The congener-specific levels calculated in the media were adjusted by the 2,3,7,8-TCDD-TEF to arrive at risk values for 2,3,7,8-tetrachlorodibenzo(*p*)dioxin-toxicity equivalents (TCDD-TEQ). The congeners modeled are listed below:

- Dioxins
  2,3,7,8 - Tetrachlorodibenzo(*p*)dioxin (TCDD)
  1,2,3,7,8 - Pentachlorodibenzodioxin (PeCDD)
  1,2,3,7,8,9 - Hexachlorodibenzodioxin (HxCDD)
  1,2,3,4,7,8 - Hexachlorodibenzodioxin (HxCDD)
  1,2,3,6,7,8 - Hexachlorodibenzodioxin (HxCDD)
  1,2,3,4,6,7,8 - Heptachlorodibenzodioxin (HpCDD)
  1,2,3,4,6,7,8,9 - Octachlorodibenzodioxin (OCDD)

- Furans
  2,3,7,8 - Tetrachlorodibenzofuran (TCDF)
  1,2,3,7,8 - Pentachlorodibenzofuran (PeCDF)
  2,3,4,7,8 - Pentachlorodibenzofuran (PeCDF)
  1,2,3,6,7,8 - Hexachlorodibenzofuran (HxCDF)
  2,3,4,6,7,8 - Hexachlorodibenzofuran (HxCDF)
  1,2,3,4,7,8 - Hexachlorodibenzofuran (HxCDF)
  1,2,3,7,8,9 - Hexachlorodibenzofuran (HxCDF)
  1,2,3,4,6,7,8 - Heptachlorodibenzofuran (HpCDF)
  1,2,3,4,7,8,9 - Heptachlorodibenzofuran (HpCDF)
  1,2,3,4,6,7,8,9 - Octachlorodibenzofuran (OCDF)

The 12 metals modeled in the analysis were:

Antimony	Cadmium	Selenium
Arsenic	Chromium (III & VI)	Silver
Barium	Lead	Thallium
Beryllium	Nickel	

All constituents considered were modeled to arrive at oral and inhalation cancer and noncancer risks if the appropriate health benchmarks were available.

- Inhalation and ingestion cancer risks were estimated for 2,3,7,8-TCDD-TEQ. Breast milk concentrations of 2,3,7,8-TCDD-TEQ were also estimated to compare to background levels in breast milk.

- Inhalation cancer risks were estimated for arsenic, beryllium, cadmium, chromium VI, and nickel.

- Oral cancer risks were estimated for arsenic and beryllium.

- Inhalation noncancer hazard quotients were estimated for barium and hydrogen chloride.

- Oral noncancer hazard quotients were estimated for antimony, arsenic, barium, beryllium, cadmium, chromium III, chromium VI, nickel, selenium, silver, and thallium.

- Lead was modeled to soil concentration levels only, for comparison with a soil lead level of concern of 400 ppm.

3. Pathways and Scenarios

a. Pathways

Figures I.1 through I.10 depict the pathways modeled in the analysis. The pathways by which the populations were exposed included

- Inhalation of pollutants in air (Figure I.1)
- Ingestion of contaminated soil (Figure I.2)
- Ingestion of contaminated produce (Figures I.3 and I.4)
- Ingestion of contaminated beef (Figure I.5)
- Ingestion of contaminated milk (Figure I.6)
- Ingestion of contaminated pork (Figure I.7)

- Ingestion of contaminated poultry (Figure I.8)
- Ingestion of contaminated fish (Figure I.9)
- Ingestion of contaminated drinking water (Figure I.10).

Drinking water risks were evaluated if surface waterbodies were identified as sources of drinking water in the area. Each individual was assumed to be exposed at some level via all pathways. Modeling of the pathways varied between the scenarios based on

- Levels of contamination - based on proximity to the facility
- Fraction of what was consumed that was contaminated
- Variations in consumption rates between adults and children
- Increases in fish consumption rates for fishers.

b. Scenarios

Two types of scenarios were modeled, those that represented the general population and those that addressed the exposures of special subpopulations. Figure I.11 depicts the scenarios modeled and serves as a key to each of the individual scenario figures that follow.

The lifetime individual risk to the typically exposed individual in the general population was estimated from air dispersion and deposition values that averaged the exposure within 20 kilometers of the facilities. The typical scenarios attempt to characterize what the average person would be exposed to within the population of interest. The selection of 20 kilometers to represent the average level of exposure was based on the balance between the exposures over a larger area which would represent a larger population but would be at lower levels, and those over a smaller area, representing fewer but more highly exposed individuals. The general population scenarios modeled were

- Typical Resident (Figure I.12)
- Typical Farmer (Figure I.13)
- Typical Resident - Child (Figure I.14).

Special subpopulations modeled included farmers and fishers as well as other groups whose activities increased their exposures. Locations that were more highly impacted by the facilities were identified through land use information and were used for estimating the exposures of the special subpopulations. The special subpopulation scenarios modeled were

- Subsistence Beef Farmer (Figure I.15)
- Subsistence Dairy Farmer (Figure I.16)
- Subsistence Dairy Farmer - Child (Figure I.17)

- Subsistence Pork Farmer (Figure I.18)
- Subsistence Poultry Farmer (Figure I.19)
- Subsistence Fisher (Figure I.20)
- Recreational Fisher (Figure I.21)
- Home Gardener (Figure I.22)
- Home Gardener - Child (Figure I.23).

Although the subsistence farmer scenarios (e.g., beef, dairy, pork, and poultry) assume that essentially all of the corresponding animal commodities that are consumed are home produced, only one type of animal is assumed to be raised in each scenario. Consumption of the food obtained from that animal is assumed to be the same as that of the general population. Similarly, essentially all of the fruits and vegetables that are consumed are assumed to be homegrown in the subsistence farmer scenarios. Selected child scenarios were modeled to highlight the child's increased consumption per body weight of soil, fruits and vegetables, and milk.

For the fisher scenarios, essentially all of the fish consumed are assumed to be caught in the local waterbody. Although the subsistence fisher is assumed to reside and fish in the same watershed, the recreational fisher may reside anywhere within 20 kilometers of the facility.

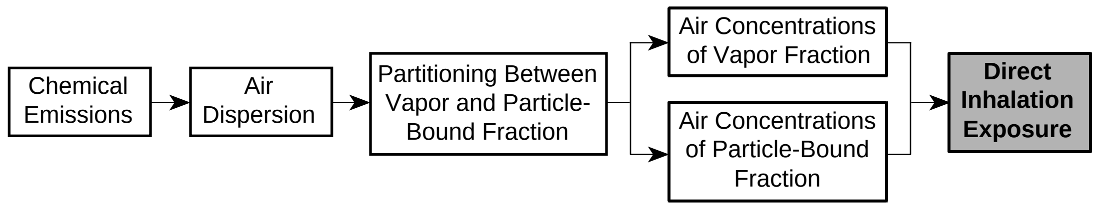

Figure I.1 Direct Inhalation Pathway

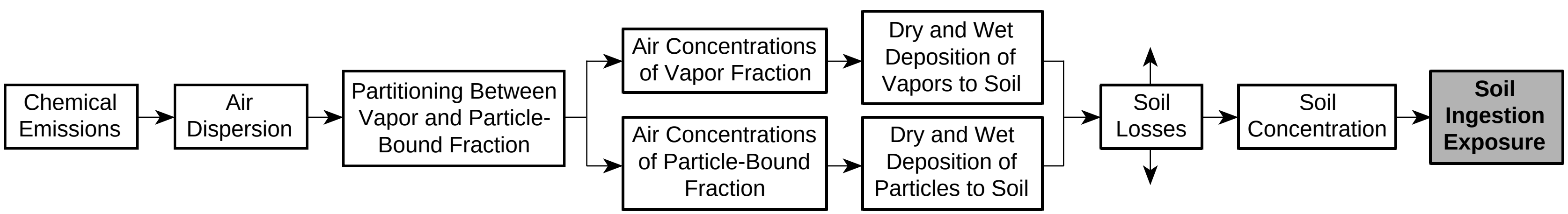

Figure I.2 Soil Ingestion Pathway

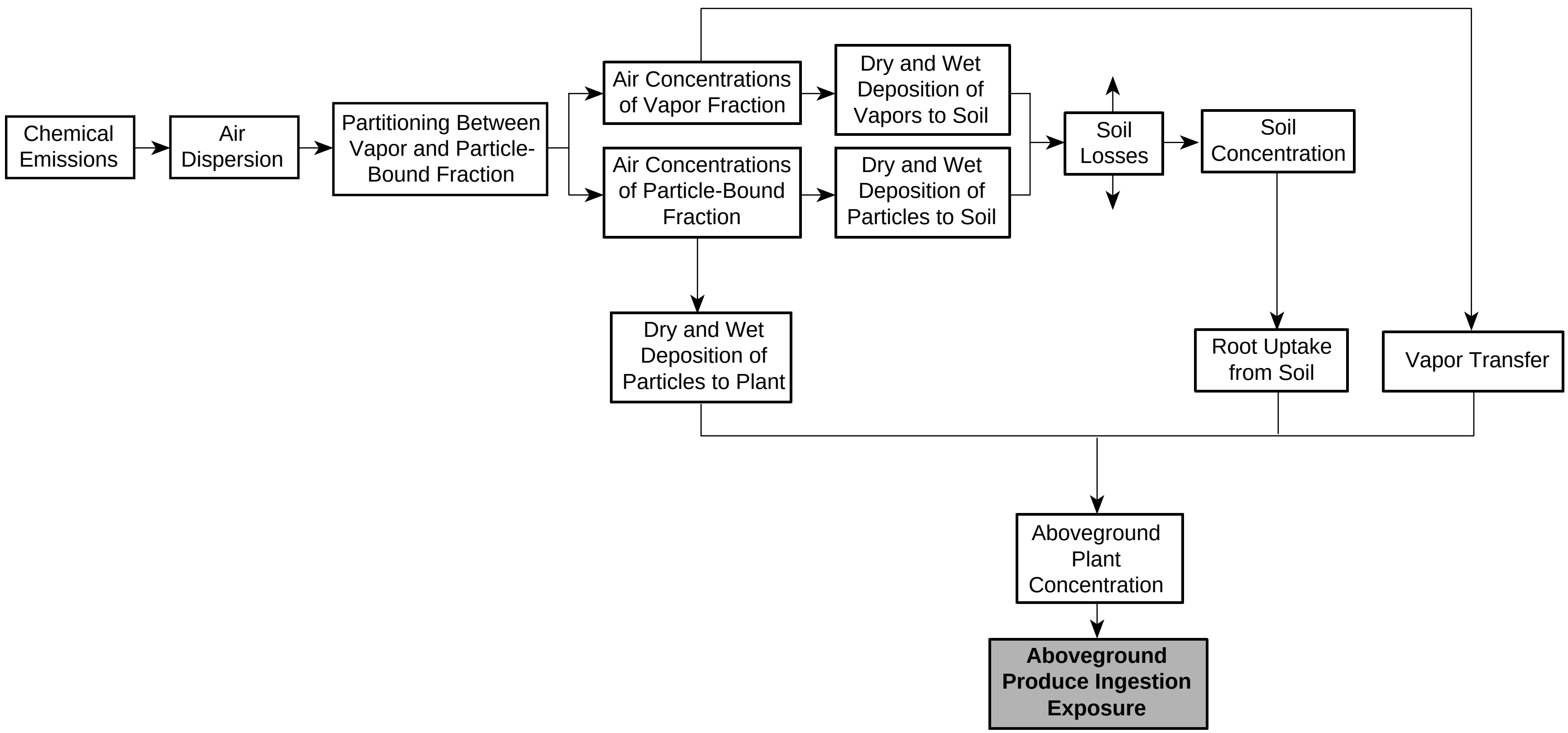

Figure I.3 Aboveground Produce Ingestion Pathway

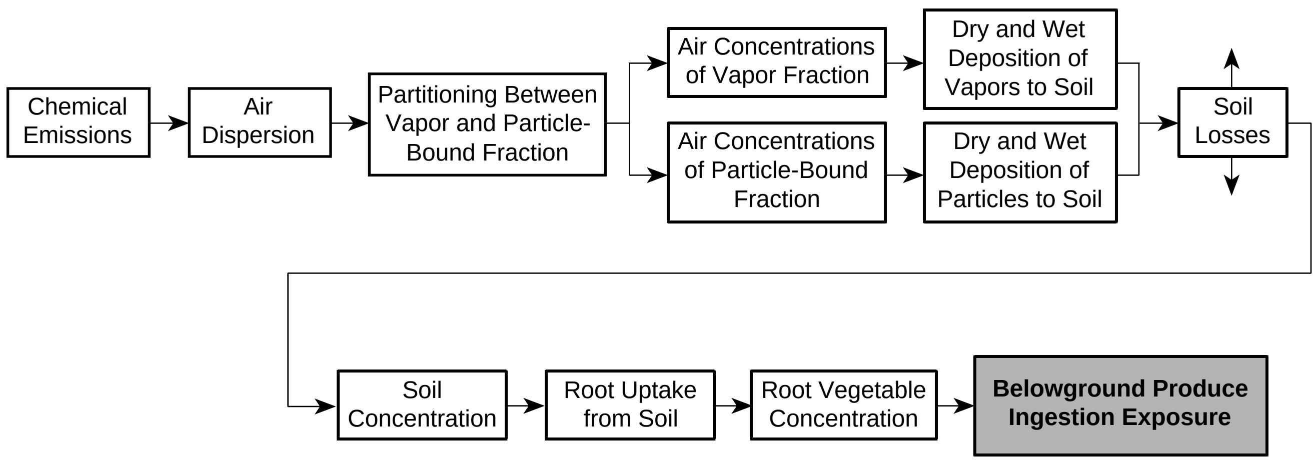

Figure I.4 Belowground Produce Ingestion Pathway

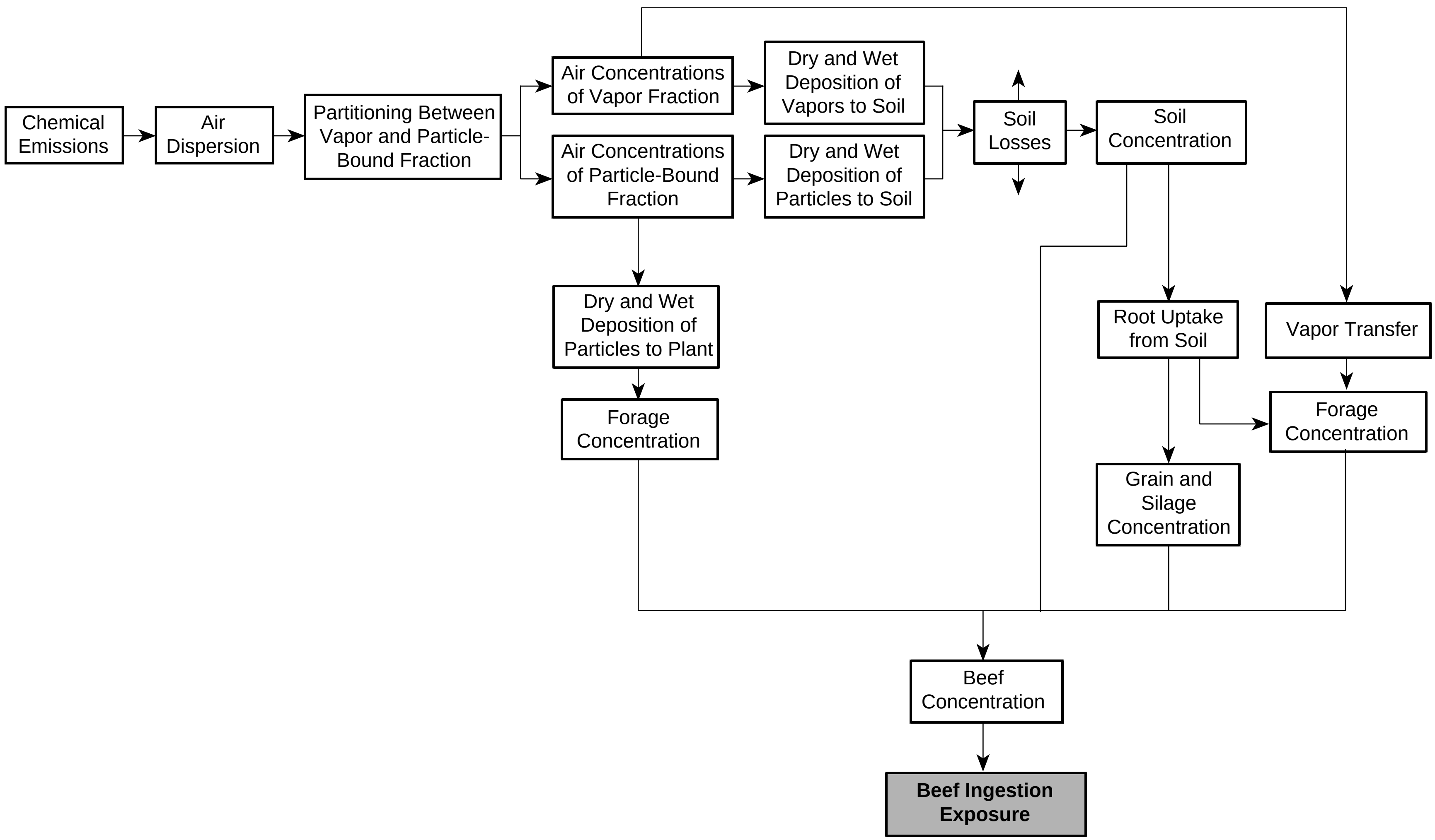

Figure I.5 Beef Ingestion Pathway

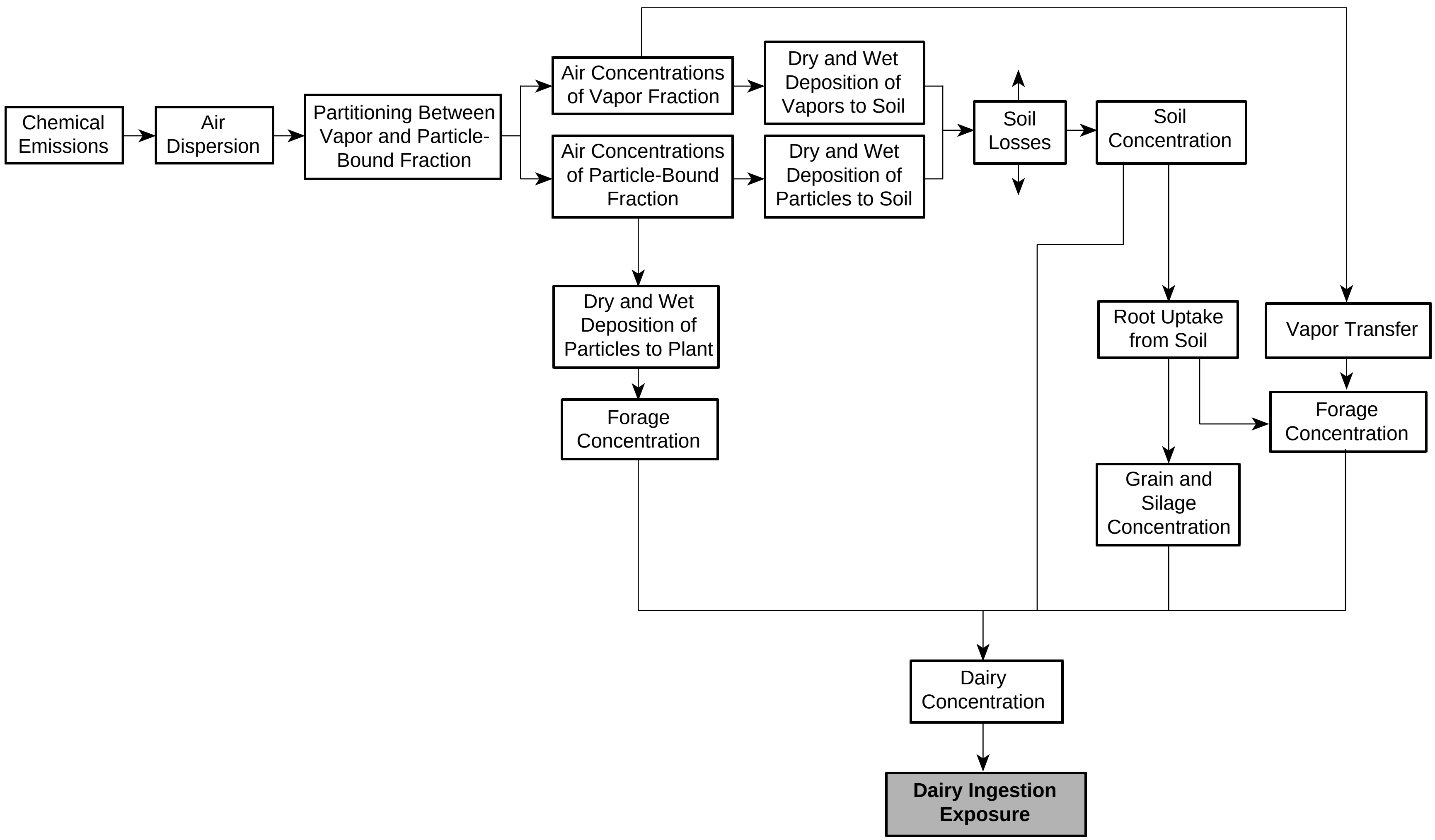

Figure I.6 Dairy Ingestion Pathway

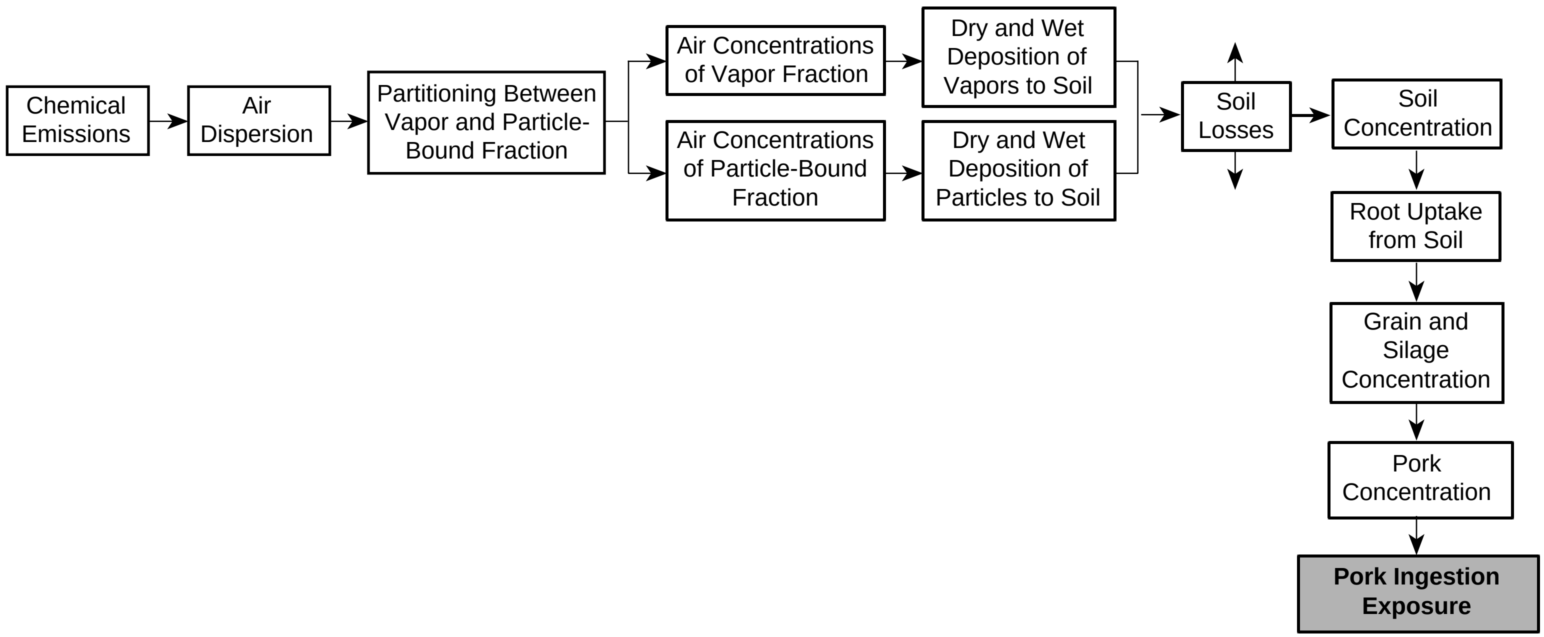

Figure I.7 Pork Ingestion Pathway

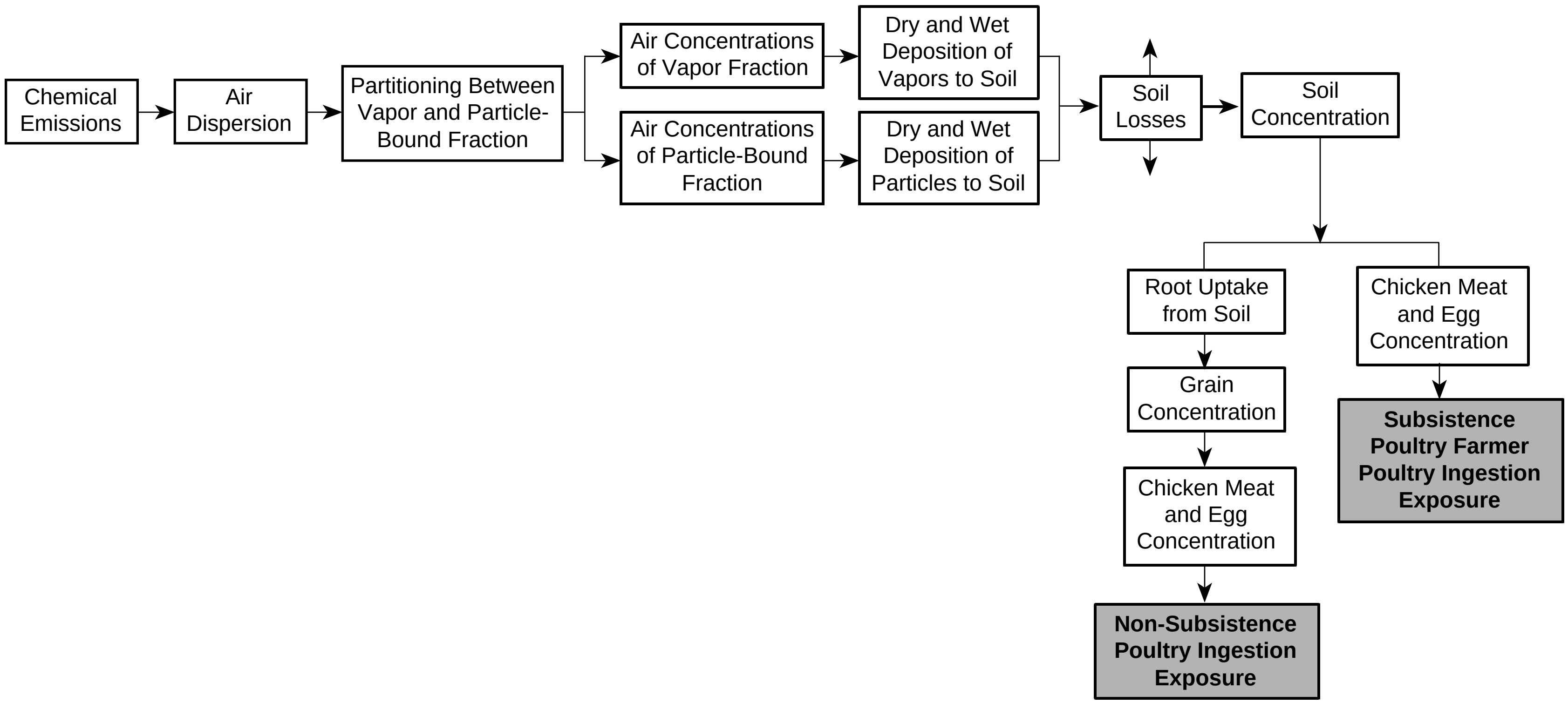

Figure I.8 Poultry Ingestion Pathway

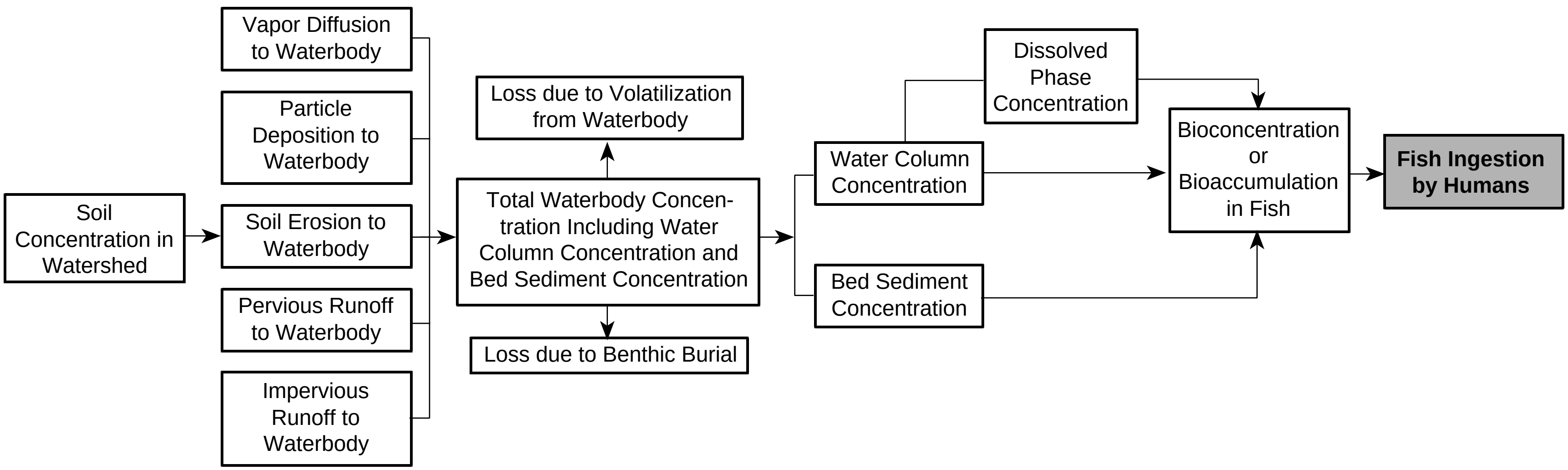

Figure I.9 Fish Ingestion Pathway

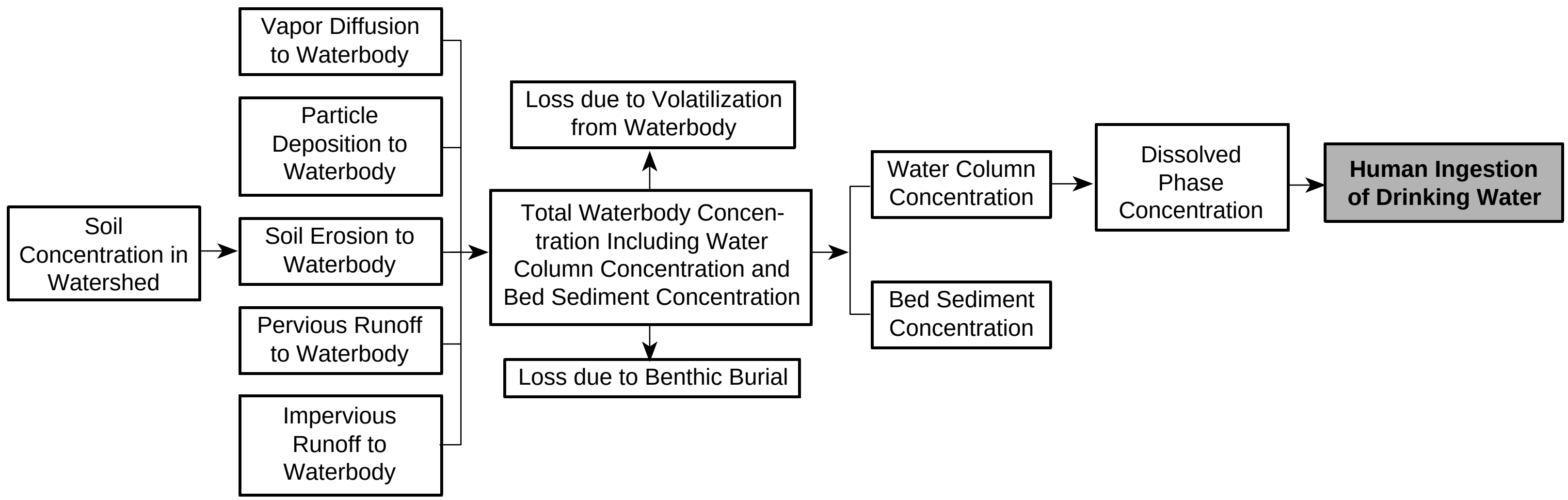

Figure I.10 Drinking Water Ingestion Pathway

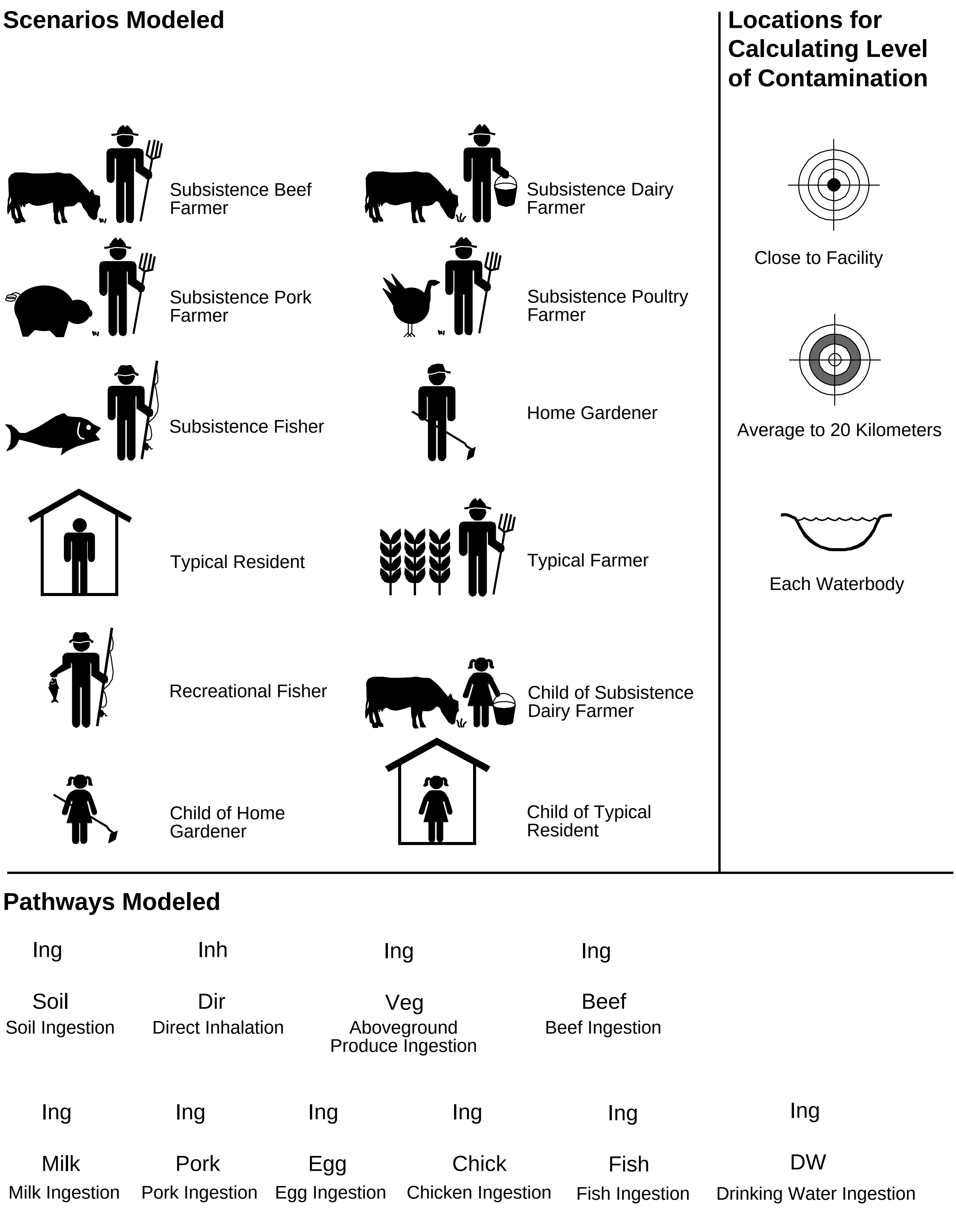

Figure I.11 Key for Scenario, Pathway, and Location Icons

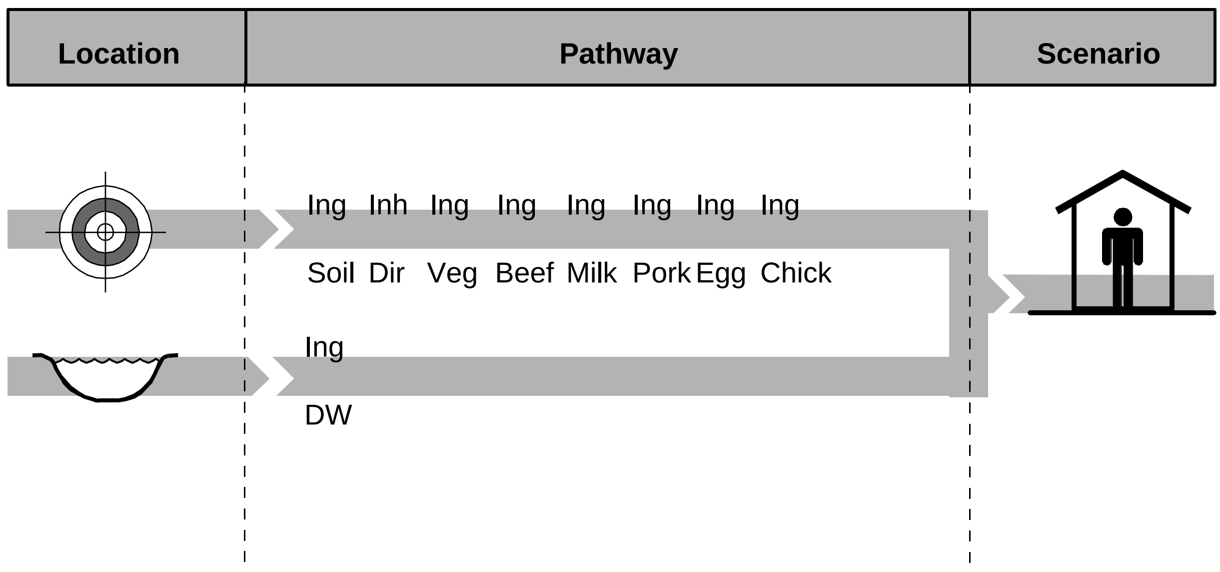

Figure I.12 Typical Resident Scenario

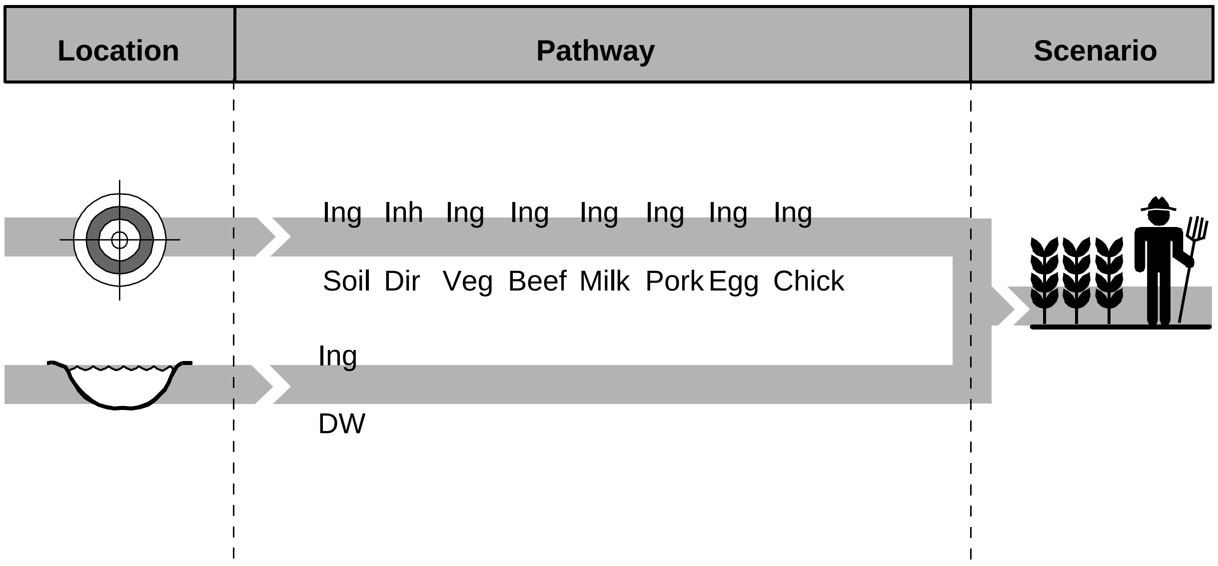

Figure I.13 Typical Farmer Scenario

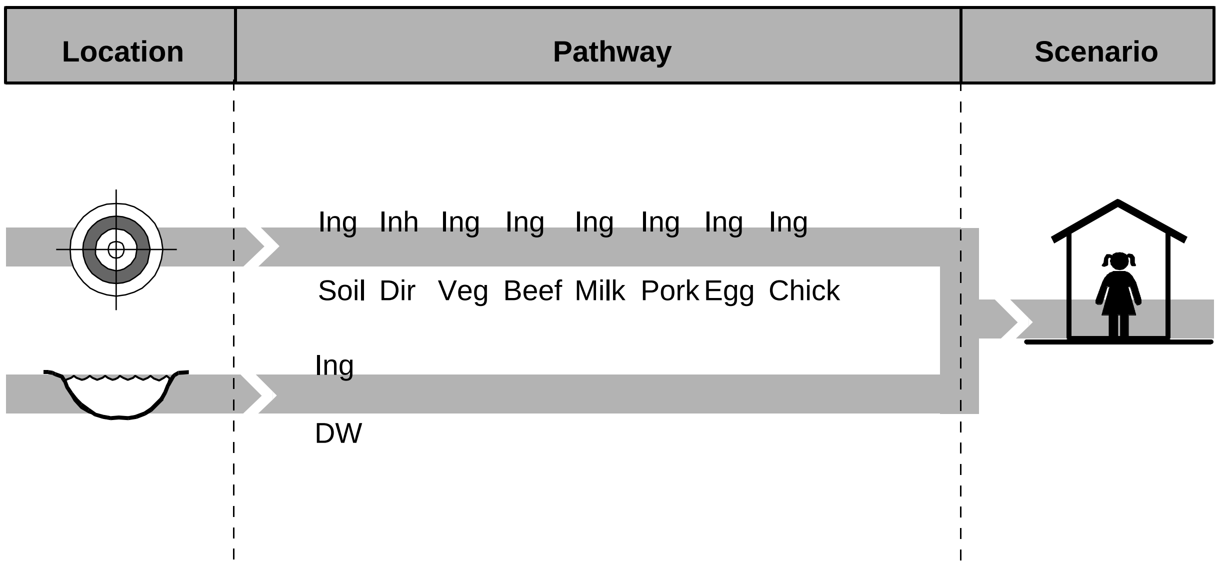

Figure I.14 Child of Typical Resident Scenario

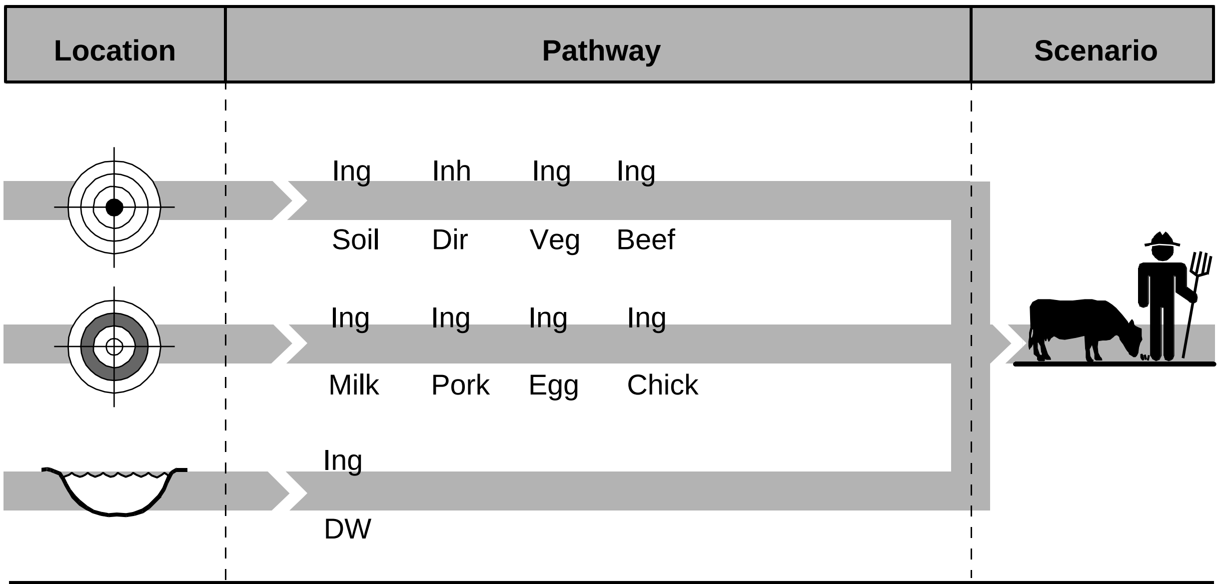

Figure I.15 Subsistence Beef Farmer Scenario

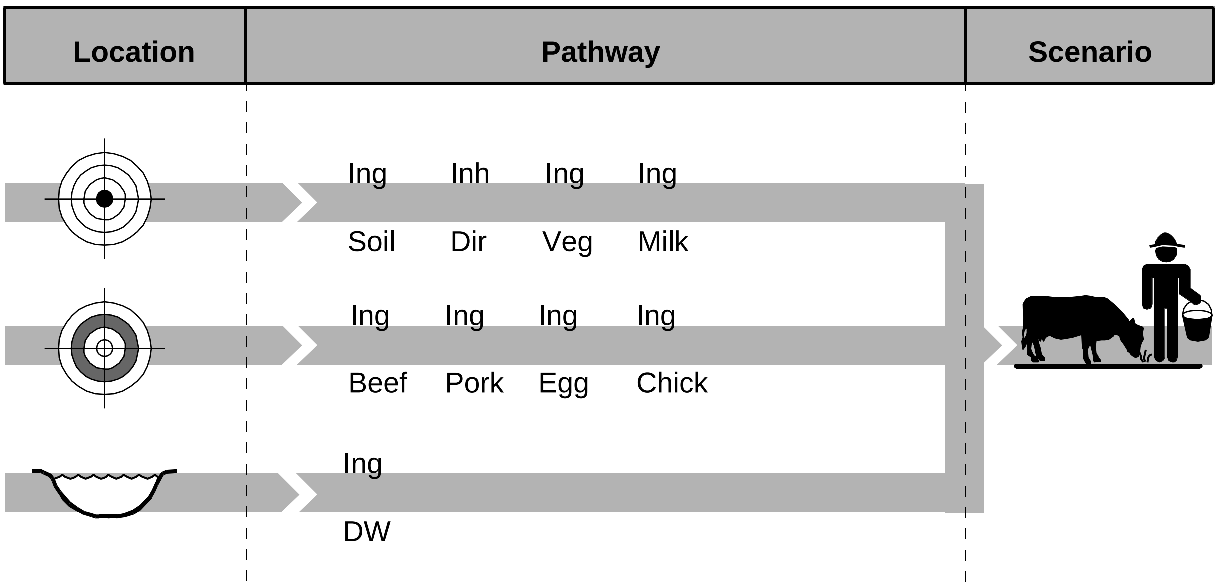

Figure I.16 Subsistence Dairy Farmer Scenario

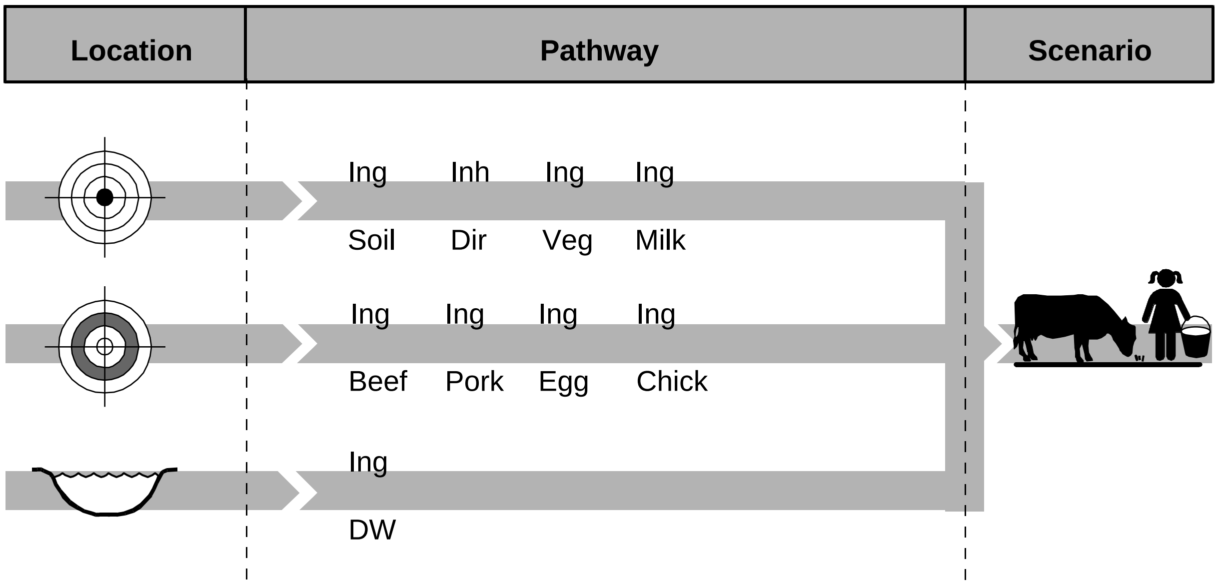

Figure I.17 Child of Subsistence Dairy Farmer Scenario

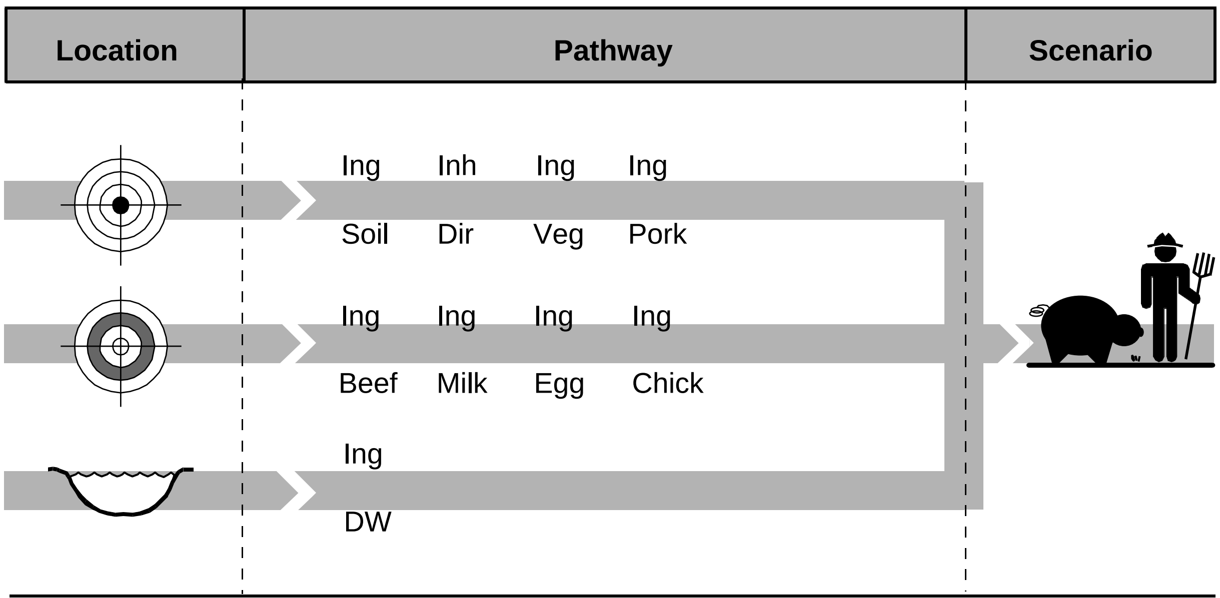

Figure I.18 Subsistence Pork Farmer Scenario

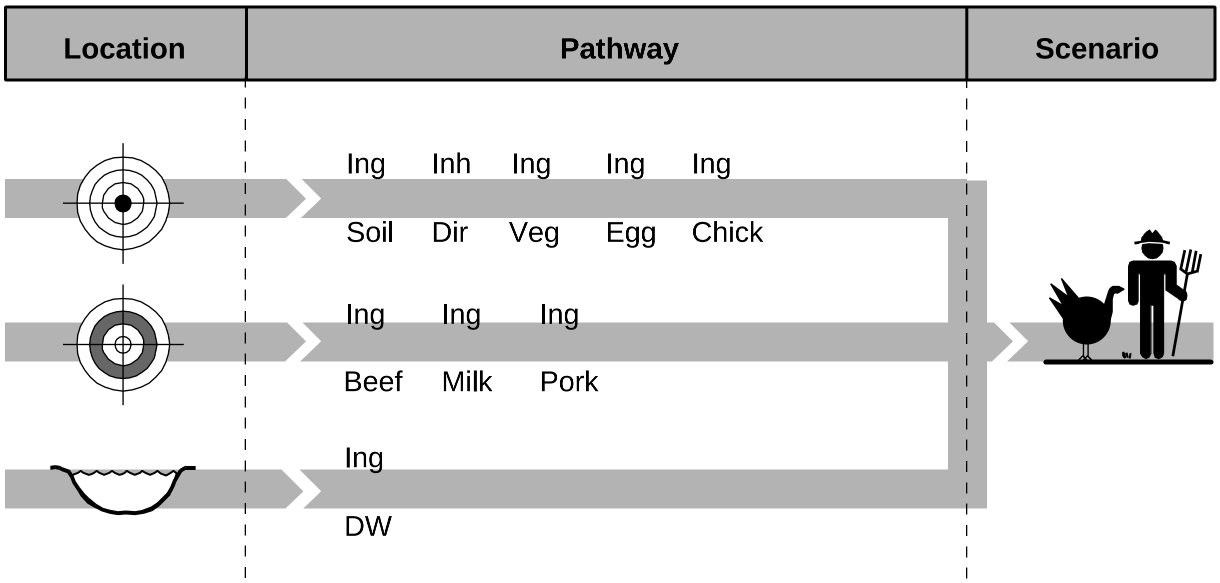

Figure I.19 Subsistence Poultry Farmer Scenario

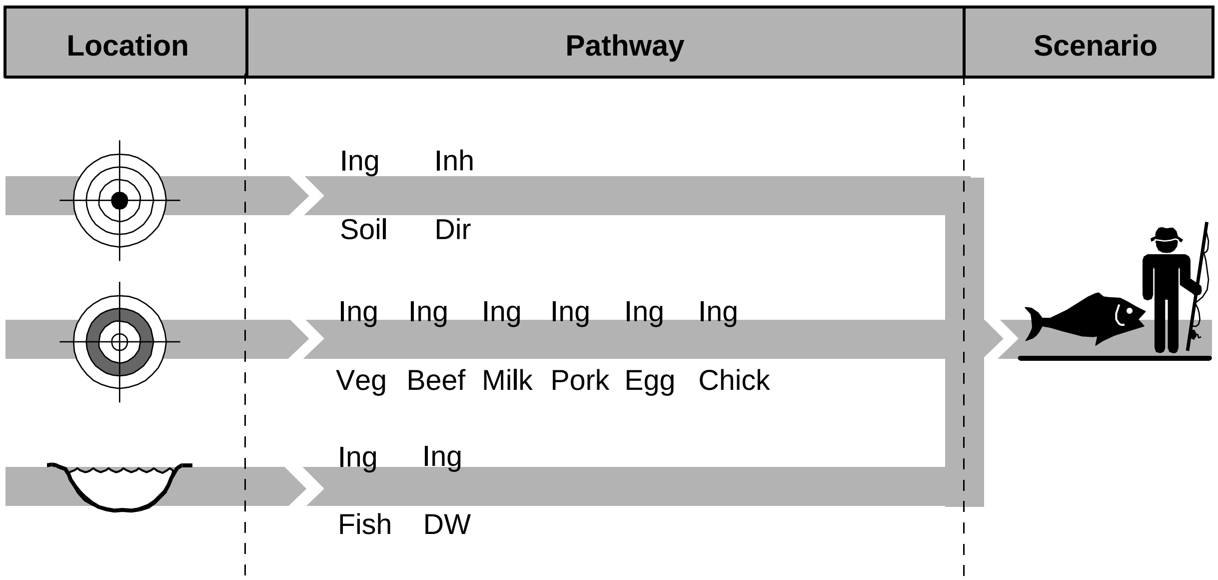

Figure I.20 Subsistence Fisher Scenario

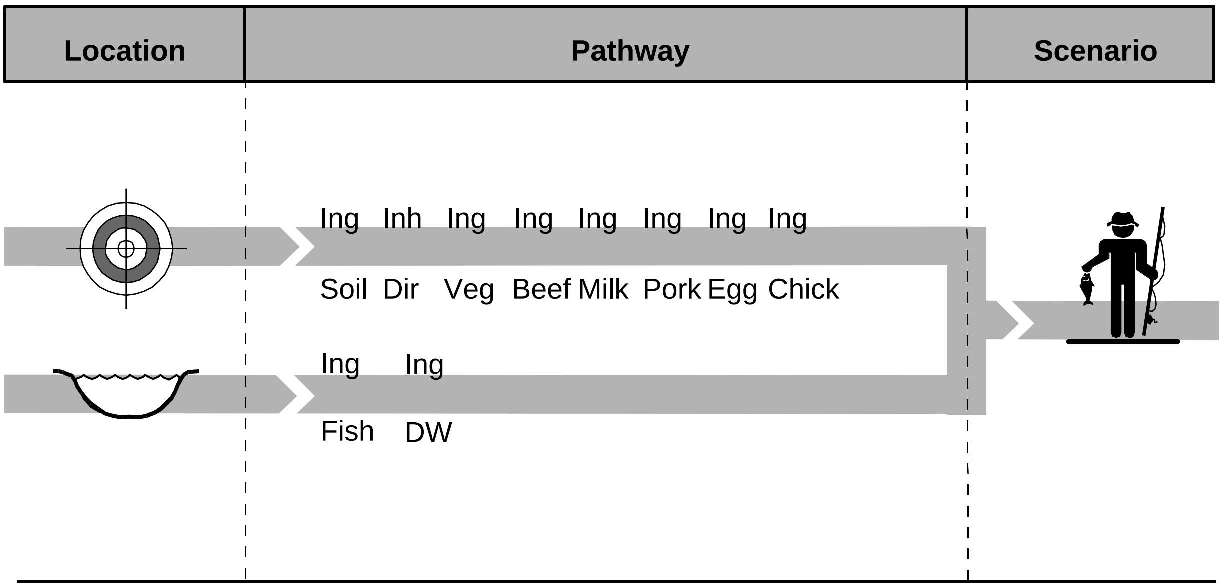

Figure I.21 Recreational Fisher Scenario

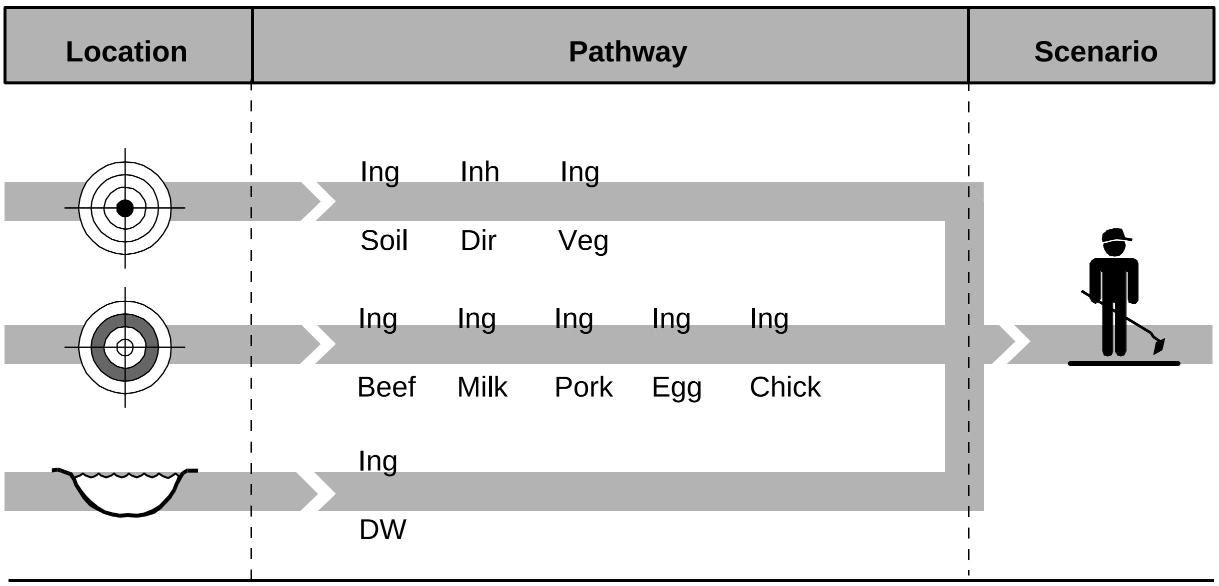

Figure I.22 Home Gardener Scenario

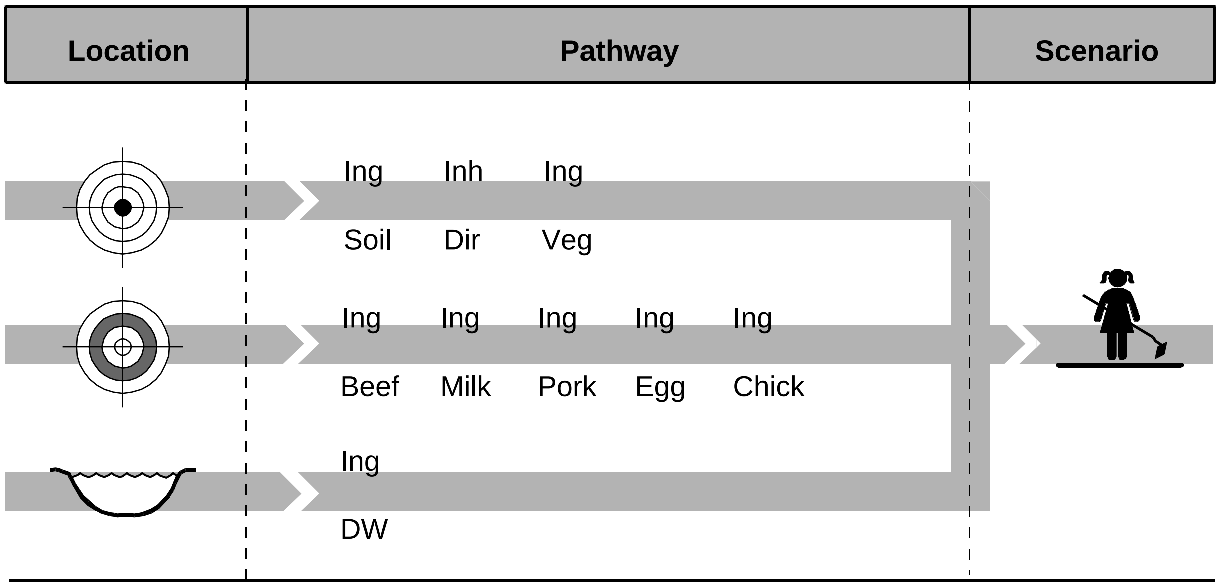

Figure I.23 Child of Home Gardener Scenario

c. Types of Estimates

All fate and transport and exposure variables were set to central tendency values (near 50th percentile) or best estimated values. To characterize high-end exposures for a given population scenario, selected exposure variables were set to high-end (near 90th percentile) values. In addition, for characterizing high-end exposures for the baseline, emissions were also set to high-end values. By setting only a few variables to high end it is more likely that the risks estimated will not be so high as to be unlikely to occur. The exposure variables, which are varied between central tendency and high end, and their values are presented in Table I.1.

Table I.1 Central Tendency and High-End Exposure Parameter Values

Exposure Parameter	Central Tendency	High End	Source
Exposure Duration			
Child	6 years		U.S. EPA (1990a)
Residents and Fishers	9 years	30 years	U.S. EPA (1990a)
Farmers	20 years (assumption)	40 years	U.S. EPA (1994b)
Contaminated Fraction (Farmers assumed to produce fruits and vegetables and one animal commodity)			
Subsistence Farmers	1.0		Assumption
Typical Farmers			U.S. EPA (1990a) (beef values assumed for pork & poultry)
Dairy	0.40	0.75	
Beef, pork, or poultry	0.44	0.75	
Vegetables	0.25	0.40	
Home Gardeners	0.25	0.40	U.S. EPA (1990a)

d. Baseline Risk Estimates

Baseline risk estimates were developed to reflect estimates of the risks resulting from current emissions levels. EPA provided stack gas emission concentrations that reflected the central tendency and high end of values obtained from stack sampling for trial burns and compliance tests (U.S. EPA, 1995f). The emissions estimates were classified by type of device for the three types studied. Facility-specific volumetric flow rates and operating hours were applied to the stack gas concentrations to arrive at the emission rates used in the analysis. Nationally averaged central tendency and high-end emission estimates were used to quantify the baseline risks. Dioxin and furan emission rates and fate and transport values used in the analysis were congener-specific.

e. Proposed Regulatory Alternatives

Risk estimates were also developed for proposed regulatory alternative levels. These levels are the proposed floor, for new and existing sources, and the proposed beyond the floor (BTF) level, for new and existing sources (U.S. EPA, 1995g). EPA is also requesting comment on alternative floor levels. The risks for these levels were also calculated; those results are presented in Section IV, Risk Characterization. For the proposed regulatory levels, the metal limit is set for a group of metals (grouped by volatility). In the assessment, the limit on the group of metals was assumed to be the amount of each individual metal emitted. This assumption was made to find the maximum risk for each individual metal. The regulatory alternative emission levels modeled are presented in Table I.2.

Table I.2 Stack Gas Concentrations of Regulatory Alternative Levels Modeled

Chemical	Source	Existing Sources		New Sources	
		MACT Floor	Beyond the Floor	MACT Floor	Beyond the Floor
2,3,7,8-TCDD-TEQ (ng/dscm @ 7% O_2)	Incinerators (Central Tendency/High End)	0.2/4.0	0.2	0.2/4.0	0.2
	Cement kilns (Central Tendency/High End)	0.2/1.4	0.2	0.2/1.4	0.2
	Lightweight aggregate kilns	0.2	0.2	0.2	0.2
Hydrogen chloride (ppmv @ 7% O_2)	Incinerators	96	96	97	25
	Cement kilns	270	270	270	25
	Lightweight aggregate kilns	1400	210	36	25
Semivolatile metals (µg/dscm @ 7% O_2)					
Cadmium	Incinerators	120	120	120	35
Lead	Cement kilns	34	34	34	35
	Lightweight aggregate kilns	7.4	7.4	4	35
Low-volatility metals (µg/dscm @ 7% 0_2)					
Antimony Arsenic Beryllium Chromium III & VI	Incinerators	110	110	110	35
	Cement kilns	67	67	26	26
	Lightweight aggregate kilns	230	230	36	35

4. Ecological Risk

Risks to freshwater aquatic organisms and associated wildlife were assessed by comparing the estimated water concentrations of the contaminants in the waterbodies to National Ambient Water Quality Criteria (NAWQC). The results of the comparison are expressed as hazard quotients, which are the ratio of the contaminant water concentration to the NAWQC.

C. Results

1. Individual Risks

Central tendency and high-end individual risks for both cancer and noncancer effects are estimated for oral exposures to dioxins and metals for the baseline for all three types of facilities. For the maximum achievable control technology (MACT) regulatory alternatives, both central tendency and high-end individual risks are estimated for cancer effects. However, for noncancer effects, only central tendency estimates are provided.[2] In addition, for inhalation exposures, individual risks are estimated separately for both cancer and noncancer effects for the most exposed individual (MEI).[3] The results tables present the range of risks over the facility types and environmental settings by presenting the lowest and highest risk for each facility type and exposure level (i.e., central tendency and high end).

a. Dioxins

Lifetime individual risk estimates exceeded 10^{-5} for many of the special subpopulations for exposures to dioxin. Table I.3 lists the range of lifetime individual risk estimates over the subsistence scenarios modeled. Only the lightweight aggregate kilns, with low stack emissions of dioxin compounds, showed maximum baseline risk estimates below 1 in a million.

Because of the bioaccumulation potential of dioxin in tissue for the animals modeled, the animal ingestion pathways were responsible for the risk estimates shown in Table I.3. Ingestion of beef, dairy, poultry, and fish all showed similar levels of risk for the subsistence scenarios.

[2] Only central tendency estimates are provided for noncancer effects because high-end estimates for noncancer effects were made for only the typical farmer and home gardener scenarios (see Table I.1) and the results differed little from the central tendency estimates.

[3] Inhalation risks are presented separately because the highest inhalation exposures generally occur at a different location (e.g., residence) than do the highest oral exposures (e.g., a nearby farm).

Table I.3 Range of 2,3,7,8-TCDD-TEQ Ingestion Individual Risk Results over Subsistence Scenarios

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Baseline				
Incinerators	2E-9	2E-6	2E-7	9E-5
Cement kilns	1E-8	2E-6	4E-7	9E-5
Lightweight aggregate kilns	2E-9	3E-7	9E-9	4E-7
Proposed Floor - Existing and New Sources				
Incinerators	3E-9	2E-6	1E-7	5E-5
Cement kilns	4E-9	1E-6	6E-8	2E-5
Lightweight aggregate kilns*	1E-8	2E-6	3E-8	
Proposed BTF - Existing and New Sources				
Incinerators*	3E-9	2E-6	6E-9	
Cement kilns	4E-9	1E-6	8E-9	2E-6
Lightweight aggregate kilns*	1E-8	2E-6	3E-8	

* For the scenario that gave the highest risk (the Subsistence Dairy Farmer Child), there is no high-end characterization (See Table I.1).

The general population's risk estimates were lower than those of the special subpopulations. Presented in Table I.4, the typical farmer's risk estimates ranged up to 5×10^{-6} for the high-end baseline estimates. The risks were lower than the subsistence scenario's because the animal products ingested by the general population were modeled as having a lower level of contamination (reflecting an average contamination level out to 20 kilometers from the sites) and because the fraction contaminated for the general population was assumed to be lower than the fraction in the subsistence scenarios. The typical resident's highest risks were similar to those of the typical farmer.

Inhalation risks for the maximally exposed individual remained below 10^{-5} for baseline and the proposed regulatory alternatives (see Table I.5).

Dioxin exposures to nursing infants through the breast milk pathway were compared to similar exposures originating from background dioxin levels. Table I.6 summarizes the range of breast milk exposure ratios calculated over the subsistence scenarios. Exposures over and above background levels are of concern because it is thought that adverse impacts on developmental biology may be occurring at or within an order of magnitude of current average background exposures (U.S. EPA, 1994b). Infants that are breast fed are expected to be among the most highly exposed and most susceptible human populations.

Table I.4 Range of 2,3,7,8-TCDD-TEQ Ingestion Individual Risk Results for Typical Farmer Scenario

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Baseline				
Incinerators	2E-9	1E-8	1E-7	1E-6
Cement kilns	1E-8	1E-7	4E-7	5E-6
Lightweight aggregate kilns	1E-9	3E-9	3E-9	9E-9
Proposed Floor - Existing and New Sources				
Incinerators	2E-9	1E-8	7E-8	6E-7
Cement kilns	4E-9	5E-8	6E-8	9E-7
Lightweight aggregate kilns	6E-9	2E-8	1E-8	3E-8
Proposed BTF - Existing and New Sources				
Incinerators	2E-9	1E-8	3E-9	3E-8
Cement kilns	4E-9	5E-8	8E-9	1E-7
Lightweight aggregate kilns	6E-9	2E-8	1E-8	3E-8

Table I.5 Dioxin/Furan Inhalation Individual Risk Estimates for the Maximally Exposed Individual

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Baseline				
Incinerators	2E-9	6E-9	2E-7	8E-7
Cement kilns	1E-9	1E-8	7E-8	7E-7
Lightweight aggregate kilns	1E-9	2E-9	7E-9	1E-8
Proposed Floor - Existing and New Sources				
Incinerators	2E-9	6E-9	1E-7	5E-7
Cement kilns	4E-10	4E-9	1E-8	1E-7
Lightweight aggregate kilns	5E-9	1E-8	3E-8	4E-8
Proposed BTF - Existing and New Sources				
Incinerators	2E-9	6E-9	6E-9	2E-8
Cement kilns	4E-10	4E-9	2E-9	2E-8
Lightweight aggregate kilns	5E-9	1E-8	3E-8	4E-8

Table I.6 Ratio of Infant 2,3,7,8-TCDD-TEQ Exposure Through Breastmilk to Background (50 pg/kg/d) Over All Subsistence Scenarios

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Baseline				
Incinerators	0.00002	0.02	0.0008	0.6
Cement kilns	0.00006	0.08	0.0004	0.9
Lightweight aggregate kilns	0.00001	0.002	0.00001	0.003
Proposed Floor - Existing and New Sources				
Incinerators	0.00002	0.02	0.0004	0.3
Cement kilns	0.00002	0.03	0.00007	0.2
Lightweight aggregate kilns	0.00006	0.008		
Proposed BTF - Existing and New Sources				
Incinerators	0.00002	0.02		
Cement kilns	0.00002	0.03		
Lightweight aggregate kilns	0.00006	0.008		

b. Metals

The ranges of ingestion risks and hazard quotients calculated over the special subpopulations are presented in Table I.7. Due to the way that the proposed levels are set (U.S. EPA, 1995g) and the assumption that each metal is emitted at the limit for its volatility group, risks often increase above the baseline levels for the regulatory options. Baseline hazard quotients for those metals that do not have proposed regulatory levels are presented in Table I.8. Because consensus health benchmarks for lead were not available, soil lead ratios are used to present the lead modeling results. The soil lead ratios are presented in Table I.9. Table I.10 presents the inhalation hazard quotients for hydrogen chloride emissions. Baseline hazard quotients only exceed 1 for the lightweight aggregate kilns. With the proposed floor, the hazard quotient for the lightweight aggregate kilns is lowered to 1. Inhalation risks for all metals remained below 10^{-5} for the baseline and the regulatory alternative levels. Metal inhalation risks are presented in Table I.11 for those metals with proposed regulatory options, and Table I.12 for those without.

Table I.7 Range of Metal Individual Ingestion Risk Estimates over All Special Subpopulation Scenarios

Facility Type	Central Tendency		High End	
	Low	High	Low	High
ANTIMONY				
Baseline				
Incinerators	HQ = 0	HQ = 0.005	HQ = 0	HQ = 0.2
Cement kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0.004
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Proposed Floor - Existing Sources				
Incinerators	HQ = 0	HQ = 0.04		
Cement kilns	HQ = 0	HQ = 0.003		
Lightweight aggregate kilns	HQ = 0	HQ = 0.002		
Alternative Floor - Existing Sources				
Incinerators	HQ = 0	HQ = 0.009		
Cement kilns	HQ = 0	HQ = 0.001		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Proposed Floor - New Sources				
Incinerators	HQ = 0	HQ = 0.04		
Cement kilns	HQ = 0	HQ = 0.001		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Proposed BTF - New Sources				
Incinerators	HQ = 0	HQ = 0.01		
Cement kilns	HQ = 0	HQ = 0.001		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
CEM Compliance Options - New Sources				
Incinerators	HQ = 0	HQ = 0.03		
Cement kilns	HQ = 0	HQ = 0.003		
Lightweight aggregate kilns	HQ = 0	HQ = 0.001		

NOTE: HQ = 0 indicates a hazard quotient less than 0.001.

Table I.7 (continued…)

Facility Type	Central Tendency		High End	
	Low	High	Low	High
ARSENIC				
Baseline				
Incinerators	6E-11 / HQ = 0	2E-7 / HQ = 0.004	2E-9 / HQ = 0	4E-6 / HQ = 0.05
Cement kilns	3E-11 / HQ = 0	3E-8 / HQ = 0.001	7E-10 / HQ = 0	5E-7 / HQ = 0.003
Lightweight aggregate kilns	3E-11 / HQ = 0	4E-8 / HQ = 0.001	8E-10 / HQ = 0	3E-7 / HQ = 0.007
Proposed Floor - Existing Sources				
Incinerators	1E-9 / HQ = 0	4E-6 / HQ = 0.09	4E-9	8E-6
Cement kilns	7E-10 / HQ = 0	6E-7 / HQ = 0.02	2E-9	2E-6
Lightweight aggregate kilns*	3E-9 / HQ = 0	3E-6 / HQ = 0.08	9E-9	
Alternative Floor - Existing Sources				
Incinerators	3E-10 / HQ = 0	9E-7 / HQ = 0.02	1E-9	2E-6
Cement kilns	2E-10 / HQ = 0	2E-7 / HQ = 0.007	7E-10	5E-7
Lightweight aggregate kilns*	4E-10 / HQ = 0	5E-7 / HQ = 0.01	1E-9	
Proposed Floor - New Sources				
Incinerators	1E-9 / HQ = 0	4E-6 / HQ = 0.09	4E-9	8E-6
Cement kilns	3E-10 / HQ = 0	2E-7 / HQ = 0.009	1E-9	7E-7
Lightweight aggregate kilns*	4E-10 / HQ = 0	5E-7 / HQ = 0.01	1E-9	
Proposed BTF - New Sources				
Incinerators	4E-10 / HQ = 0	1E-6 / HQ = 0.03	1E-9	3E-6
Cement kilns	3E-10 / HQ = 0	2E-7 / HQ = 0.009	1E-9	7E-7
Lightweight aggregate kilns*	4E-10 / HQ = 0	4E-7 / HQ = 0.01	2E-9	
CEM Compliance Option - New Sources				
Incinerators	1E-9 / HQ = 0	3E-6 / HQ = 0.06	3E-9	6E-6
Cement kilns	8E-10 / HQ = 0	8E-7 / HQ = 0.03	3E-9	2E-6
Lightweight aggregate kilns*	1E-9 / HQ = 0	1E-6 / HQ = 0.03	3E-9	

NOTE: HQ = 0 indicates a hazard quotient less than 0.001.
* For the scenario that gave the highest risk for central tendency (the Subsistence Dairy Farmer Child), there is no high-end characterization.

Table I.7 (continued…)

Facility Type	Central Tendency		High End	
	Low	High	Low	High
BERYLLIUM[a]				
Baseline				
Incinerators	3E-11 / HQ = 0	5E-9 / HQ = 0	6E-10 / HQ = 0	5E-8 / HQ = 0
Cement kilns	5E-11 / HQ = 0	2E-8 / HQ = 0	6E-10 / HQ = 0	1E-7 / HQ = 0
Lightweight aggregate kilns	4E-11 / HQ = 0	8E-9 / HQ = 0	5E-10 / HQ = 0	4E-8 / HQ = 0
Proposed Floor - Existing Sources				
Incinerators	8E-9 / HQ = 0	1E-6 / HQ = 0.001		
Cement kilns	9E-9 / HQ = 0	4E-6 / HQ = 0.002		
Lightweight aggregate kilns	2E-8 / HQ = 0	4E-6 / HQ = 0.002		
Alternative Floor - Existing Sources				
Incinerators	2E-9 / HQ = 0	3E-7 / HQ = 0		
Cement kilns	3E-9 / HQ = 0	1E-6/HQ = 0.001		
Lightweight aggregate kilns	3E-9 / HQ = 0	7E-7 / HQ = 0		
Proposed Floor - New Sources				
Incinerators	8E-9 / HQ = 0	1E-6 / HQ = 0.001		
Cement kilns	4E-9 / HQ = 0	2E-6 / HQ = 0.001		
Lightweight aggregate kilns	3E-9 / HQ = 0	7E-7 / HQ = 0		
Proposed BTF - New Sources				
Incinerators	2E-9 / HQ = 0	4E-7 / HQ = 0		
Cement kilns	4E-9 / HQ = 0	1E-6 / HQ = 0.001		
Lightweight aggregate kilns	3E-9 / HQ = 0	6E-7 / HQ = 0		
CEM Compliance Option - New Sources				
Incinerators	6E-9 / HQ = 0	9E-7 / HQ = 0		
Cement kilns	1E-8 / HQ = 0	5E-6 / HQ = 0.002		
Lightweight aggregate kilns	8E-9 / HQ = 0	1E-6 / HQ = 0.001		

NOTE: HQ = 0 indicates a hazard quotient less than 0.001. [a] High-end cancer risks for beryllium's MACT options were not calculated because the majority of scenarios responsible for the highest risks were child scenarios, with no change in exposure duration between central tendency and high end.

Table I.7 (continued…)

Facility Type	Central Tendency		High End	
	Low	High	Low	High
CADMIUM				
Baseline				
Incinerators	HQ = 0	HQ = 0.001	HQ = 0	HQ = 0.02
Cement kilns	HQ = 0	HQ = 0.001	HQ = 0	HQ = 0.01
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0.003
Proposed Floor - Existing Sources				
Incinerators	HQ = 0	HQ = 0.01		
Cement kilns	HQ = 0	HQ = 0.004		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Alternative Floor - Existing Sources				
Incinerators	HQ = 0	HQ = 0.003		
Cement kilns	HQ = 0	HQ = 0.01		
Lightweight aggregate kilns	HQ = 0	HQ = 0.001		
Proposed Floor - New Sources				
Incinerators	HQ = 0.001	HQ = 0.01		
Cement kilns	HQ = 0	HQ = 0.004		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Proposed BTF - New Sources				
Incinerators	HQ = 0	HQ = 0.004		
Cement kilns	HQ = 0	HQ = 0.005		
Lightweight aggregate kilns	HQ = 0	HQ = 0.001		
CEM Compliance Option - New Sources				
Incinerators	HQ = 0	HQ = 0.004		
Cement kilns	HQ = 0	HQ = 0.005		
Lightweight aggregate kilns	HQ = 0	HQ = 0.001		

NOTE: HQ =0 indicates a hazard quotient less than 0.001.

Table I.7 (continued…)

Facility Type	Central Tendency		High End	
	Low	High	Low	High
CHROMIUM III				
Baseline				
Incinerators	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Cement kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Proposed Floor - Existing Sources				
Incinerators	HQ = 0	HQ = 0		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Alternative Floor - Existing Sources				
Incinerators	HQ = 0	HQ = 0		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Proposed Floor - New Sources				
Incinerators	HQ = 0	HQ = 0		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Proposed BTF - New Sources				
Incinerators	HQ = 0	HQ = 0		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
CEM Compliance Option - New Sources				
Incinerators	HQ = 0	HQ = 0		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0		

NOTE: HQ = 0 indicates a hazard quotient less than 0.001.

Table I.7 (continued…)

Facility Type	Central Tendency		High End	
	Low	High	Low	High
CHROMIUM VI				
Baseline				
Incinerators	HQ = 0	HQ = 0	HQ = 0	HQ = 0.001
Cement kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Proposed Floor - Existing Sources				
Incinerators	HQ = 0	HQ = 0.003		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0.001		
Alternative Floor - Existing Sources				
Incinerators	HQ = 0	HQ = 0.001		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Proposed Floor - New Sources				
Incinerators	HQ = 0	HQ = 0.003		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
Proposed BTF - New Sources				
Incinerators	HQ = 0	HQ = 0.001		
Cement kilns	HQ = 0	HQ = 0		
Lightweight aggregate kilns	HQ = 0	HQ = 0		
CEM Compliance Option - New Sources				
Incinerators	HQ = 0	HQ = 0.002		
Cement kilns	HQ = 0	HQ = 0.001		
Lightweight aggregate kilns	HQ = 0	HQ = 0.001		

NOTE: HQ = 0 indicates a hazard quotient less than 0.001.

Table I.8 Individual Ingestion Risk Estimates over All Special Subpopulation Scenarios - Metals Without Regulatory Options

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Baseline				
Barium				
Incinerators	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Cement kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0.003
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Nickel				
Incinerators	HQ = 0	HQ = 0	HQ = 0	HQ = 0.002
Cement kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Selenium				
Incinerators	HQ = 0	HQ = 0	HQ = 0	HQ = 0.003
Cement kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0.004
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0
Silver				
Incinerators	HQ = 0	HQ = 0.001	HQ = 0	HQ = 0.005
Cement kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0.002
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0	HQ = 0.001
Thallium				
Incinerators	HQ = 0	HQ = 0.02	HQ = 0	HQ = 0.1
Cement kilns	HQ = 0	HQ = 0.01	HQ = 0	HQ = 0.1
Lightweight aggregate kilns	HQ = 0	HQ = 0.001	HQ = 0	HQ = 0.002

NOTE: HQ = 0 indicates a hazard quotient less than 0.001.

Table I.9 Soil Lead Ratios
Modeled Soil Lead Concentrations Divided by 400 ppm

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Baseline				
Incinerators	0.000006	0.0006	0.0002	0.01
Cement kilns	0.00001	0.006	0.0001	0.06
Lightweight aggregate kilns	0.000001	0.00008	0.00004	0.006
Proposed Floor - Existing Sources				
Incinerators	0.000008	0.0008		
Cement kilns	0.000003	0.002		
Lightweight aggregate kilns	0.0000004	0.00004		
Proposed Floor - New Sources				
Incinerators	0.000008	0.0008		
Cement kilns	0.000003	0.002		
Lightweight aggregate kilns	0.0000002	0.00002		
Proposed BTF - New Sources				
Incinerators	0.000002	0.0002		
Cement kilns	0.000003	0.002		
Lightweight aggregate kilns	0.000002	0.0002		

Table I.10 Hydrochloric Acid Inhalation Individual Risks Estimate for the Maximally Exposed Individual

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Baseline				
Incinerators	HQ = 0.001	HQ = 0.003	HQ = 0.01	HQ = 0.05
Cement kilns	HQ = 0	HQ = 0.004	HQ = 0.004	HQ = 0.04
Lightweight aggregate kilns	HQ = 0.1	HQ = 0.2	HQ = 2	HQ = 4
Proposed Floor - Existing Sources				
Incinerators	HQ = 0.02	HQ = 0.05		
Cement kilns	HQ = 0.01	HQ = 0.1		
Lightweight aggregate kilns	HQ = 0.8	HQ = 1		
Proposed BTF - Existing Sources				
Incinerators	HQ = 0.02	HQ = 0.05		
Cement kilns	HQ = 0.01	HQ = 0.1		
Lightweight aggregate kilns	HQ = 0.1	HQ = 0.2		
Proposed Floor - New Sources				
Incinerators	HQ = 0.02	HQ = 0.05		
Cement kilns	HQ = 0.01	HQ = 0.1		
Lightweight aggregate kilns	HQ = 0.02	HQ = 0.04		
Proposed BTF - New Sources				
Incinerators	HQ = 0.004	HQ = 0.01		
Cement kilns	HQ = 0.001	HQ = 0.01		
Lightweight aggregate kilns	HQ = 0.01	HQ = 0.02		

NOTE: HQ = 0 indicates a hazard quotient less than 0.001.

Table I.11 Inhalation Individual Risk Estimates for the Maximally Exposed Individual - Metals With Regulatory Options

Facility Type	Central Tendency		High End	
	Low	High	Low	High
ARSENIC				
Baseline				
Incinerators	4E-9	2E-8	2E-7	6E-7
Cement kilns	6E-10	7E-9	1E-8	1E-7
Lightweight aggregate kilns	9E-9	2E-8	2E-7	4E-7
Proposed Floor - Existing Sources				
Incinerators	9E-8	4E-7	4E-7	1E-6
Cement kilns	1E-8	2E-7	4E-8	4E-7
Lightweight aggregate kilns	8E-7	2E-6	2E-6	5E-6
Proposed Floor - New Sources				
Incinerators	9E-8	4E-7	4E-7	1E-6
Cement kilns	5E-9	6E-8	1E-8	1E-7
Lightweight aggregate kilns	1E-7	3E-7	4E-7	7E-7
Proposed BTF - New Sources				
Incinerators	3E-8	1E-7	1E-7	4E-7
Cement kilns	5E-9	6E-8	1E-8	1E-7
Lightweight aggregate kilns	1E-7	3E-7	4E-7	7E-7

Table I.11 (continued)

Facility Type	Central Tendency		High End	
	Low	High	Low	High
BERYLLIUM				
Baseline				
Incinerators	2E-10	7E-10	7E-9	3E-8
Cement kilns	5E-11	5E-10	1E-9	1E-8
Lightweight aggregate kilns	9E-10	1E-9	1E-8	2E-8
Proposed Floor - Existing Sources				
Incinerators	5E-8	2E-7	2E-7	7E-7
Cement kilns	9E-9	9E-8	3E-8	3E-7
Lightweight aggregate kilns	5E-7	5E-7	1E-6	2E-6
Proposed Floor - New Sources				
Incinerators	5E-8	2E-7	2E-7	7E-7
Cement kilns	3E-9	3E-8	1E-8	1E-7
Lightweight aggregate kilns	7E-8	8E-8	2E-7	3E-7
Proposed BTF - New Sources				
Incinerators	2E-8	6E-8	5E-8	2E-7
Cement kilns	3E-9	3E-8	1E-8	1E-7
Lightweight aggregate kilns	7E-8	8E-8	2E-7	3E-7

Table I.11 (continued)

Facility Type	Central Tendency		High End	
	Low	High	Low	High
CADMIUM				
Baseline				
Incinerators	4E-9	1E-8	2E-7	7E-7
Cement kilns	1E-9	1E-8	4E-8	4E-7
Lightweight aggregate kilns	1E-8	2E-8	3E-7	5E-7
Proposed Floor - Existing Sources				
Incinerators	5E-8	1E-7	2E-7	5E-7
Cement kilns	3E-9	3E-8	1E-8	1E-7
Lightweight aggregate kilns	1E-8	2E-8	4E-8	6E-8
Proposed Floor - New Sources				
Incinerators	5E-8	1E-7	2E-7	5E-7
Cement kilns	3E-9	3E-8	1E-8	1E-7
Lightweight aggregate kilns	6E-9	1E-8	2E-8	3E-8
Proposed BTF - New Sources				
Incinerators	1E-8	3E-8	4E-8	2E-7
Cement kilns	3E-9	3E-8	1E-8	1E-7
Lightweight aggregate kilns	5E-8	1E-7	2E-7	3E-7

Table I.11 (continued)

Facility Type	Central Tendency		High End	
	Low	High	Low	High
CHROMIUM VI				
Baseline				
Incinerators	7E-9	3E-8	4E-7	2E-6
Cement kilns	1E-9	1E-8	3E-8	3E-7
Lightweight aggregate kilns	1E-8	2E-8	2E-7	4E-7
Proposed Floor - Existing Sources				
Incinerators	3E-7	1E-6	8E-7	4E-6
Cement kilns	4E-8	4E-7	2E-7	2E-6
Lightweight aggregate kilns	2E-6	4E-6	7E-6	1E-5
Proposed Floor - New Sources				
Incinerators	3E-7	1E-6	8E-7	4E-6
Cement kilns	2E-8	2E-7	6E-8	6E-7
Lightweight aggregate kilns	3E-7	6E-7	1E-6	2E-6
Proposed BTF - New Sources				
Incinerators	8E-8	3E-7	3E-7	1E-6
Cement kilns	2E-8	2E-7	6E-8	6E-7
Lightweight aggregate kilns	3E-7	5E-7	1E-6	2E-6

Table I.12 Inhalation Individual Risk Estimates for the Maximally Exposed Individual - Metals without Regulatory Options

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Nickel - Baseline				
Incinerators	2E-9	5E-9	5E-8	2E-7
Cement kilns	2E-10	2E-9	3E-9	3E-8
Lightweight aggregate kilns	8E-9	1E-8	2E-7	3E-7
Barium - Baseline				
Incinerators	HQ = 0	HQ = 0	HQ = 0.001	HQ = 0.003
Cement kilns	HQ = 0	HQ = 0.001	HQ = 0.001	HQ = 0.006
Lightweight aggregate kilns	HQ = 0	HQ = 0	HQ = 0.001	HQ = 0.002

NOTE: HQ = 0 indicates a hazard quotient less than 0.001.

2. Ecological Risks

For the baseline emissions, with the exception of 2,3,7,8-TCDD-TEQ, all constituents were present in the water column at concentrations significantly below the NAWQC. The NAWQC for 2,3,7,8-TCDD-TEQ is based on the bioaccumulation potential of the chemicals and was developed for the Great Lakes Water Quality Initiative (U.S. EPA, 1995a). Since the criteria are based on reproductive effects, some effect on wildlife populations may occur if the criteria are exceeded.

As shown in Table I.13, both the baseline and the proposed floor hazard quotients for 2,3,7,8-TCDD-TEQ for both incinerators and cement kilns exceed 1.

Table I.13 Ratios of Total Water Column Concentrations for the Various MACT Options for Dioxins

Facility Type	Central Tendency		High End	
	Low	High	Low	High
Baseline				
Incinerators	0.008	0.4	0.2	10
Cement kilns	0.1	9	1	100
Lightweight aggregate kilns	0.003	0.2	0.003	0.2
Proposed Floor - Existing and New Sources				
Incinerators	0.008	0.4	0.1	7
Cement kilns	0.05	4	0.2	20
Lightweight aggregate kilns	0.02	0.8		
Proposed Beyond the Floor - Existing and New Sources				
Incinerators	0.008	0.4		
Cement kilns	0.05	4		
Lightweight aggregate kilns	0.02	0.8		

D. Key Assumptions and Uncertainties

In order to conduct the complex modeling analysis used in this risk assessment, a large number of assumptions were made regarding the scenarios to be modeled as well as the specific parameter values used in the models. The key assumptions that lead to the greatest uncertainties in the results are summarized below.

1. Emissions, Dispersion, Deposition, and Land Use

The major assumptions that affect the results of the dispersion and deposition models are the emissions rates and meteorologic conditions. For dioxins and furans, the analysis is also sensitive to the emission of the specific 2,3,7,8- substituted congener in the emissions.

Constituent emissions were calculated by multiplying each facility's average gas flow rate by the 50th percentile concentration from all facilities in that category for which data were available (for a central tendency individual risk estimate) and by the 90th percentile concentration (for a high-end individual risk estimate). The emissions data used to derive the 50th and 90th percentile concentrations are presented in the engineering background document (U.S. EPA, 1995f).

Because concentration data on each constituent were not available for all facilities, the available data were assumed to be representative of all facilities. It is not known how valid that assumption is or in what direction (if any) a bias may exist. In addition, most of the data were from trial burn tests, where the facility is establishing its operating envelope. Because a facility is likely to try and establish as broad an operating envelope as possible, trial burn data may overestimate emissions under normal operating conditions. The magnitude of this potential overestimation is not known.

Air dispersion and deposition modeling was conducted using models that are not fully developed. For example, dry deposition of vapor phase materials is not treated in the model; instead, estimates of vapor dry deposition are made external to the model. Adequate experimental data are not yet available to verify the chemical-specific deposition rates modeled. Also, long-range transport into and out of the areas examined was not modeled.

Detailed information on meteorologic conditions and land-use patterns was collected for each of the 11 case study areas. The attempt was made to identify waterbodies that are actually used for recreational fishing. High-end and central tendency individual risk estimates were then calculated for each waterbody for the baseline by varying the emissions. These individual risk estimates were then assumed to be representative across each of the facility categories. Because the number of case studies for each category is relatively small compared to the total number of facilities in each category (4/162 incinerators, 5/26 cement kilns, and 2/7 lightweight aggregate kilns), it is likely that the results do not cover the range of possible individual risks across all of the facilities.

Also, although the facilities selected were representative with respect to the range in size and geographic location, their selection was influenced by availability of appropriate meteorologic data; therefore, the 11 facilities cannot be considered statistically representative of all hazardous waste combustion units. Furthermore, small on-site incinerators are not represented by the case studies. Therefore, it is expected that the individual risk estimates overstate the risk for these types of facilities, but the extent of overestimation is unknown.

2. Environmental Fate, Transport, and Individual Exposure

With a few exceptions, the parameters that are specific to dioxins were taken from the draft EPA Dioxin Reassessment (U.S. EPA, 1994b and c). The exceptions include particle scavenging coefficients, air-to-leaf bioconcentration factors, and dry deposition velocities as well as bioconcentration factors for poultry and eggs. Because data on a number of these parameters are extremely limited, some uncertainty is introduced in the analysis, the extent of which is unknown.

Plant uptake, accumulation in soils, bioaccumulation in cattle, transport to surface waters through erosion and runoff, partitioning in the waterbody, bioaccumulation in fish, and consumption by recreational fishers were all evaluated using information from existing guidance (U.S. EPA, 1993a). Although there can be considerable variability and uncertainty in the parameters defining each of these processes, for this analysis, parameter values were selected that were near the midpoint of the ranges of values available. The lack of validation of results from combining the various fate and transport models together is acknowledged, and, in this case, the direction in which the final results may be biased cannot be estimated.

The routes of exposure that showed the highest potential risk from dioxins were ingestion of contaminated fish, ingestion of contaminated beef and dairy products from cattle grazing in areas affected by deposition, and ingestion of contaminated poultry and eggs from chickens exposed to contaminated soils. The highest risk route of exposure varied depending on land use patterns and proximity of the facility to surface waters. An attempt was made to identify the location of actual farms where subsistence type activities might be occurring; however, this could not be confirmed.

II. Exposure Methodology

A. Introduction and Overview

This section presents the exposure assessment methodology used in the risk analysis. For this analysis, national contaminant emissions data were modeled using site-specific data from 11 representative combustion sources. The site-specific data included facility parameters, meteorologic data, topography, and land-use data. The selected sources included four hazardous waste incinerators, five cement kilns burning hazardous wastes, and two lightweight aggregate kilns burning hazardous wastes. The model sources and their environmental settings are identified as Cases A through K. A discussion of each case is included in Appendix A.

Indirect exposures to dioxins, furans, and metals were estimated for two types of population groups - the general population and other subpopulations. The special subpopulations included subsistence beef, dairy, pork, and poultry farmers; subsistence and recreational fishers; and home gardeners. Indirect exposures to children of subsistence dairy farmers and home gardeners were also modeled. The selected child scenarios were modeled to highlight the child's increased consumption per body weight of soil, fruits and vegetables, and milk. The subsistence farmers' consumption of the commodity that they produced was assumed to be exclusive.

The level of contamination is calculated from the scenario's location with respect to the facility. Local officials were contacted to determine locations of nearby individuals who appeared to exhibit subsistence type behaviors. From the identified locations and the air dispersion and deposition modeling results, locations of individuals who were most impacted by the facilities were selected. These locations were used as the probable locations of subsistence subpopulations for the analysis.

The general population scenarios included residents (adult and child) and farmers. The impact of combustion emissions for these "typical" scenarios was set to reflect average impacts within 20 kilometers of the facilities. The selection of a distance of 20 kilometers to be used as an estimate of the average level of risk to residents around a facility was based on judgment as to the balance between exposures over a larger area, representing a larger population but with lower risks, and a smaller area, representing fewer, but more highly exposed, individuals. For inhalation exposures, risks were estimated for a most exposed individual corresponding to a residence located at the point of maximum estimated ambient air concentrations.

The routes by which subsistence and typical populations were exposed included inhalation of pollutants in the air, ingestion of contaminated soil, ingestion of contaminated produce, and ingestion of contaminated beef, milk, fish, poultry, and pork. Drinking water risks were evaluated if surface waterbodies were identified as sources of drinking water in the area.

Foods purchased in the local market included foods of local origin and foods from other sources (i.e., sources outside the area of concern). In this assessment, only foods of local origin were considered to be contaminated. Imported foods were assumed not to be contaminated by any hazardous-waste-burning sources. Food items purchased in local markets were assumed to have levels of contamination calculated from average impacts within 20 kilometers of the facility. The fraction of food produced locally that was contaminated and the fraction that was available in local markets varied by both dietary item and study case.

Three levels of exposure were calculated: central tendency, high end, and bounding. The central tendency level attempts to approximate a near 50th percentile exposure and risk. The high-end level adjusts the baseline emission levels, the fraction of commodities home produced by the typical farmer and the home gardener, and the exposure duration to near the 90th percentile level. The high-end exposure represents an exposure above the 90th percentile of the distribution of individual exposures, but not higher than the individual with the highest exposure. The bounding level analysis attempts to approximate the possible high-end risk, regardless of current land use. The bounding estimates assume that exposures occur at the location of maximum impact, or, for water pathways, from a default high-end watershed. If exposures did occur at that location or from the default watershed, then the estimated exposures would actually represent a high-end risk. Although the bounding level of risk may be unlikely, it cannot be ruled out given the large number of hazardous-waste-burning facilities and the relatively small sample size.

B. Selection of Example Facilities

The 11 facilities chosen for this assessment were selected as representative of facilities burning hazardous waste. Criteria for selection were the type and size of the facility, the availability of meteorologic data, the topography surrounding the facility, and the geographic location of the facility. All cement kilns and incinerators identified in the CETRED Document (U.S. EPA, 1994a) were considered in the selection process, with respect to the availability of meteorologic data and geographic location. However, selection of the lightweight aggregate kilns was made from an EPA database. As a result of this selection process, 11 facilities were identified, including four hazardous waste incinerators, five cement kilns that burn hazardous waste, and two lightweight aggregate kilns that burn hazardous wastes.

1. Source Characterization

a. Type of Facility

Although incinerators, cement kilns, and lightweight aggregate kilns burn similar waste and emit similar types of pollutants, differences between the types of combustion facilities exist. Kilns are typically located in rural areas, near quarries where the raw materials needed in the manufacturing process are readily available. Kilns are heavy energy users, and their throughputs and the quantity of pollutants emitted tend to be greater than those associated with incinerators. Because kilns typically have tall stacks, air concentrations of pollutants near kilns are more diluted than the air concentrations near incinerators. Incinerators tend to be located in more heavily developed industrial areas. They have smaller throughputs and emit smaller quantities of pollutants. Additionally, their stacks are proportionately shorter, which decreases the dispersion of the pollutant, thereby increasing the local air concentrations. For indirect exposures resulting from deposition, stack height is not as critical a parameter because wet deposition tends to be highest close to the stack, regardless of the relative stack height.

b. Size (Volumetric Flow Rate)

Emission estimates for the constituents of concern depend on the throughput of the facility. Because national estimates of pollutant stack gas concentrations were used, for the purpose of this assessment, the size of a facility was identified by the volumetric flow rate of its combustion stack(s). Incinerators, cement kilns, and lightweight aggregate kilns were considered independently in the selection of appropriately sized facilities. Eleven hazardous waste incinerators, sixteen cement kilns, and six lightweight aggregate kilns (identified in the CETRED Document, U.S. EPA, 1994a) were ranked by volumetric flow rate. Facilities with flow rates representative of the central tendency and high end were chosen. Facilities considered representative of the central tendency were those with flow rates ranked near the 50th percentile, and high-end facilities were considered to be those with rates near the 90th percentile.

2. Environmental Setting/Land Use

a. Availability of Meteorologic Data

Incinerators and cement kilns were considered collectively for the selection of representative meteorologic conditions. Each potential facility was examined for the availability of appropriate meteorologic data. For the purpose of this assessment, representative meteorologic data were defined as 24-h/d hourly observations from the National Weather Service (NWS), the military, or from any other reliable sources that were located near the facility and had the same spatial orientation of terrain features as the facility. Representative meteorologic data from either EPA's Office of Air Quality Planning and Standards-Technology Transfer Network (OAQPS-TTN) or the National Climatic Data Center (NCDC) were not available for all locations. Furthermore, on-site meteorologic data were not available for consideration in facility selection. The lack of representative data caused several sites to be eliminated from further consideration.

b. Topography

Topography was considered in the selection of combustion facilities because of its impact on air modeling and meteorology in the indirect exposure analysis. The effects of terrain are the changing of wind flow and the potential for extreme air concentrations and deposition rates to occur when the centerline of the elevated plume impacts upon terrain. This makes local topography important in air dispersion modeling.

The topography of the site was also a limiting factor in the selection of meteorologic data for facilities under consideration. Based on latitude and longitude, facilities were located and terrain assessed through U.S. Geological Survey (USGS) topographic maps, geographic information system (GIS) maps, and contact with EPA Regional permitting officials. Topographic maps and recommendations from Regional officials (based on site visits and the meteorologic locations used by the facilities for their current permits) were used to assess the appropriateness of available meteorologic data to the facilities on the basis of terrain features.

Some facilities with volumetric flow rates in the appropriate range were eliminated from selection because of differences in the orientation of terrain features at the facility from those at the most representative available meteorologic location. Especially in areas of complex terrain (defined as terrain rising above the final plume height), the orientation of terrain features surrounding a facility had to be similar to those at the location where the meteorologic observations were recorded.

c. Geographic Locations

Incinerators and kilns were considered collectively in the selection of facilities with representative geographic locations. The geographic location served as a surrogate for a number of site-specific variables such as precipitation, land use, agricultural practices, and surface waterbodies, all of which can have important effects on exposures. The geographic distribution of the facilities with representative volumetric flow rates, meteorologic data, and topography was examined. The final 11 sites were selected to ensure geographic diversity.

d. Results of Selection Process

Four hazardous waste incinerators, five cement kilns that burn hazardous wastes, and two lightweight aggregate kilns that burn hazardous wastes were selected for the analysis. Details concerning each of the selected facilities are provided in Appendix A.

The selected incinerators and their associated environmental settings are identified as Cases A, E, G, and I in Appendix A. The four incinerators selected represent central tendency and high-end sizes. NWS meteorologic data were used in the modeling of three of the locations. The remaining facility was modeled using NWS data substituted with site-specific winds and temperatures obtained from a local air quality management agency. Site-specific terrain data from the GIS were also used in modeling this facility. The geographic diversity for incinerators encompassed the southern, west coast, and north-central regions of the United States.

The selected cement kilns and their associated environmental settings are identified as Cases B, C, D, F, and H in Appendix A. Both central tendency and high-end flow rate cement kilns were selected. Site-specific terrain data from the GIS were used in the modeling of three of the five selected kilns. NWS meteorologic data were used in the modeling for all of the cement kilns. Geographic locations for cement kilns included the northeast, southeast, Great Lakes, and midwestern regions of the United States.

The selected lightweight aggregate kilns and their associated environmental settings are identified as Cases J and K. Both central tendency and high-end lightweight aggregate kilns were selected. Site-specific terrain data from the GIS was used in modeling one of the locations. NWS data were used in the modeling of both lightweight aggregate kilns. The facilities were located in the northeast and the southeast regions of the United States.

C. Dispersion and Deposition Modeling

1. Model Selection

ISCSTDFT (previously known as ISC-COMPDEP) is the air dispersion and deposition model developed by EPA for use in indirect exposure modeling. This model is a draft modified version of EPA's Industrial Source Complex Short Term Model (ISCST2). It is a Gaussian plume model that is applicable in simple, intermediate, and complex terrain areas. This model can simulate both wet and dry deposition and plume depletion. Therefore, ISCSTDFT was selected as the most appropriate model for use in this evaluation of combustion facilities.

In using ISCSTDFT to model the 11 combustion facilities considered in this analysis, the "default" option set for the Industrial Source Complex Model was selected. The default option set determines how ISCSTDFT calculates ambient air concentrations and depositions and includes the following:

- Default stack-tip downwash calculations
- Buoyancy-induced dispersion calculations

- Final plume rise in all calculations
- Calms processing routines
- Default wind profile exponents
- Default vertical potential temperature gradients.

PCRAMMET, PMERGE, and DEPMET are the preprocessors needed to convert the meteorologic data gathered from various sources into the format used by ISCSTDFT. PCRAMMET requires two types of meteorologic data: (1) hourly surface observation in the CD 144 format and (2) twice-daily mixing heights based on upper air observations. The output of PCRAMMET consists of hourly values of windspeed and direction, stability class, urban and rural mixing heights, and temperature.

Two meteorologic preprocessors, PMERGE and DEPMET, are used to create a meteorologic file that will allow ISCSTDFT to model wet and dry deposition. PMERGE prepares an hourly precipitation file for the modeling of wet deposition. DEPMET calculates two surface layer variables -- the Monin-Obukhov length and the friction velocity -- required for ISCSTDFT to model dry deposition. DEPMET creates the final hourly meteorologic file from the PMERGE output file, the PCRAMMET output file, and the hourly surface observations. Appendix A contains the site-specific meteorologic preprocessor inputs used in the air dispersion and deposition modeling for each facility.

2. Model Requirements

ISCSTDFT requires site-specific inputs for combustion source parameters, receptor locations, terrain features, and meteorologic data. Appendix A contains detailed information for all of the inputs required by ISCSTDFT, including the site-specific values for each facility and a summary of the sources of information.

a. Stack Parameters

Site-specific stack parameters are required for ISCSTDFT to accurately model the air concentration and deposition rates of a combustion facility. Stack parameters for each of the 11 facilities were provided through facility survey responses or obtained from the EPA database and include the following:

- Stack height (meters)
- Stack inside diameter (meters)
- Exit velocity (meters/second)
- Stack gas temperature (kelvin)
- Building heights and widths (meters).

The potential effect of building downwash was investigated for all 11 facilities to determine if nearby buildings were expected to impact the plume. In most cases the facility survey responses indicated that building downwash would not be expected. For those facilities that did not address downwash in their responses but did provide building dimension and location information, the Building Profile Input Program (BPIP) was run. The results of the investigation showed that building downwash was negligible in 9 of the 11 representative sites.

b. Setting Characterization

ISCSTDFT requires actual terrain elevations in areas of complex terrain (defined as terrain rising above the final plume height). However, the use of actual terrain features may also have significant effects in areas of intermediate terrain. In this analysis, five facilities were modeled using site-specific terrain inputs. Three of these facilities were located in areas of complex terrain, and two were in areas where terrain impacts might be expected. The remaining six facilities were in areas of relatively flat terrain and flat terrain was assumed for the air dispersion and deposition modeling. The ISCSTDFT site-specific terrain inputs consisted of elevations at specific receptor locations and gridded terrain files created using GIS programs. The gridded terrain file contained elevations at every 100 meters over a given area.

b1. Meteorologic Input Parameters

The *Guideline on Air Quality Models* (U.S. EPA, 1993c) recommends that 5 years of appropriate meteorologic data be used for making long-term estimates of ambient air concentrations and deposition rates. For most of the 11 facilities considered in this analysis, 5 years of hourly observations of surface and upper air parameters from the NWS stations selected as representative of the facilities were downloaded from the OAQPS-TTN or obtained from the National Climatic Data Center. The data that were obtained from these two sources included:

- Windspeed
- Wind direction
- Ambient temperature
- Cloud cover
- Day and nighttime (twice daily) measured mixing heights (upper air parameter).

The ISCSTDFT model also requires additional meteorologic observation elements for deposition calculations. Because these elements were not available on EPA's OAQPS-TTN, they were obtained from NCDC. These additional elements included:

- Precipitation type
- Precipitation amount
- Station pressure.

In preparing the meteorologic data, the actual anemometer height, which is the height at which the surface windspeed is actually measured, was used for each location. Anemometer heights were obtained from each station's Station Climatic Summary, available from the NCDC.

Besides these site-specific meteorologic data, the DEPMET preprocessor also requires a series of meteorologic constants that describe the location used in ISCSTDFT to model wet and dry deposition. Values for the DEPMET inputs were based on land use around each facility. The ISCSTDFT User's Guide suggested values for the DEPMET inputs based on the site-specific land use. Appendix A provides the values used for each facility modeled.

Surface roughness was the most important meteorologic constant in terms of variability of model output. Surface roughness is a measure of the variability in the heights of individual surface elements such as buildings or trees. Surface roughness was estimated using site-specific land use information. However, if the estimated surface roughness was greater than 1/20th of the anemometer height, the precept of the equations governing the model would be violated; thus a default of 1/20th of the anemometer height was substituted. The limit on the roughness height should result in a decrease in the estimate of the turbulent mixing, resulting in increased air concentrations and decreased dry deposition rates over a narrower plume width. The updated version of the meteorologic preprocessor (PCRAMMET for ISC3) contains an algorithm that compares the surface roughness at the location where the meteorologic data were collected to the surface roughness at the modeled location to make adjustments in the equations used to scale the windspeed from the height of the anemometer to the surface. Appendix A contains the value of surface roughness used for each facility modeled.

c. Receptor Characterization

c1. Residences and Farms

As discussed earlier, exposed populations were divided into two population types, the general population and other subpopulations. This difference was reflected in the ISCSTDFT air modeling. For the subpopulation locations, ISCSTDFT receptors were placed in 16 radial directions at distances of 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, and 10.0 kilometers. Subpopulation scenarios were located at the nearest corresponding receptor based on local land use information.

Local land use was obtained through telephone interviews with local planning offices, county agricultural extension agents, and/or other local officials. Information concerning nearby residents and local agricultural practices was obtained through these contacts. The contacts were also questioned concerning which waterbodies were used as sources of local drinking water and as fishing locations. From this information, sites of likely exposures were identified for the subpopulations. The following information was requested for each site during the telephone interviews:

- Location of the nearest residents in each direction from the facility
- Location of the nearest farms raising beef for personal consumption
- Location of the nearest farms raising pork for personal consumption
- Location of the nearest farms raising poultry for personal consumption
- Location of the nearest farms raising dairy cows for personal milk consumption
- Sources of local drinking water
- Nearby waterbodies used for fishing.

c2. Watersheds

For the general population (and for watershed impacts), cartesian receptors were evenly spaced every 1,000 meters out to 20 kilometers. Air concentrations and deposition rates were averaged over this area. Although these values were used to characterize the exposure to the general populations, these averages did not occur at one "typical" location. The information gathered from the telephone survey was also used, in part, to identify waterbodies and their associated watersheds. Waterbodies that served as sources of drinking water and/or fishing were selected. Another criterion for selecting waterbodies was location in relation to the facilities. For most cases, waterbodies that were within 20 kilometers of the site were selected. However, for three cases, this distance was extended to assess risks resulting from drinking water from identified drinking water sources.

All waterbodies and watersheds were located and mapped using USGS topographic maps. Areally averaged wet and dry deposition rates and vapor concentrations were calculated for each watershed and waterbody from the cartesian receptors. The maximum air concentration location in each watershed was used as the exposure location for direct inhalation and soil ingestion for the subsistence fisher. (However, the recreational fisher's direct inhalation and soil ingestion exposures were those of the general population.) The USGS maps were also used for sizing the waterbodies and watersheds.

Additional surface water parameters were determined from several other sources. The fraction of impervious watershed was based on the site-specific land use and imperviousness factors cited in Camp, Dresser, and McKee (1989). Waterbody current velocity and volumetric flow rates were either obtained from the REACH files (U.S. EPA, 1995e) or calculated. REACH files are available only for larger rivers. Volumetric flow rates for smaller rivers and for lakes were calculated as the product of the watershed area and one-half the local average annual surface runoff. The surface runoff was obtained from the *Water Atlas* (Geraghty et al., 1973). Current velocities for smaller rivers were calculated as the volumetric flow rate divided by the cross-sectional area. Current velocities are not used in the equations for lakes. Waterbody depth was obtained from site contacts or default values were applied for lakes and rivers. Appendix A contains the waterbody and watershed parameters for each case considered in this analysis.

c3. Bounding

From the air modeling results, the point of maximum vapor air concentration and the point of maximum combined (wet and dry) deposition were determined for each facility. These maximums were used in conjunction with high-end emission rates and exposure factors to estimate "bounding" risks from combustors. The maximum deposition point was used as the point of departure in estimating indirect risks. Rather than collocating the maximum air concentration and deposition values, the air concentration values associated with the receptor at the point of maximum combined deposition rate were used.

To calculate risks for fish and drinking water ingestion, additional air modeling was conducting for a bounding watershed with an area of 7,000 by 7,000 meters, centered on the point of maximum combined deposition. The bounding watershed (above the 90th percentile in an EPA database), located at the center of maximum impact, and coupled with high-end impervious area and depth, yields a bounding estimate because of the combination of high-end parameters. Although the bounding level of risk may be unlikely, it cannot be ruled out given the large number of hazardous-waste-burning facilities and the relatively small sample size. Table II.1 lists other surface water parameters that were used in defining the bounding watershed.

Table II.1. Bounding Watershed Area Parameters

Watershed Area (m^2)	Waterbody Area (m^2)	Impervious Watershed Area (m^2)	Waterbody Depth (m)
4.9E7	3.77E4	2.45E5	0.25

d. Emissions Characterization

d1. Constituents

In this analysis, emissions from combustors were characterized, in part, by constituent and amount. All emissions data were obtained from the EPA Office proposing the standards. These data were calculated from trial burn and compliance test stack sampling conducted at a series of hazardous waste combustion facilities across the United States.

Facility-specific emission rates were calculated from central tendency and high-end baseline and regulatory alternative stack gas concentrations (nanograms or micrograms per dry standard cubic meter at 7 percent oxygen). Separate stack gas concentrations were developed for each type of facility from an EPA database. The resulting emission rates in mass per second (e.g., grams per second) were calculated by multiplying the stack gas concentration by the facility-specific volumetric flow rate. The results were adjusted by the operating hours, the ratio of the facilities' annual operating hours reported in the survey responses to the hours in a year. A default value of 90 percent was used when the operating hours were not available.

For kilns and incinerators, the constituents of concern included the following congeners of polychlorinated dioxins and furans (PCDDs/PCDFs) and metal species:

- Dioxins
  2,3,7,8 - Tetrachlorodibenzo(p)dioxin (TCDD)
  1,2,3,7,8 - Pentachlorodibenzodioxin (PeCDD)
  1,2,3,7,8,9 - Hexachlorodibenzodioxin (HxCDD)
  1,2,3,4,7,8 - Hexachlorodibenzodioxin (HxCDD)
  1,2,3,6,7,8 - Hexachlorodibenzodioxin (HxCDD)
  1,2,3,4,6,7,8 - Heptachlorodibenzodioxin (HpCDD)
  1,2,3,4,5,7,8,9 - Octachlorodibenzodioxin (OCDD)

- Furans
  2,3,7,8 - Tetrachlorodibenzofuran (TCDF)
  1,2,3,7,8 - Pentachlorodibenzofuran (PeCDF)
  2,3,4,7,8 - Pentachlorodibenzofuran (PeCDF)
  1,2,3,6,7,8 - Hexachlorodibenzofuran (HxCDF)
  2,3,4,6,7,8 - Hexachlorodibenzofuran (HxCDF)
  1,2,3,4,7,8 - Hexachlorodibenzofuran (HxCDF)
  1,2,3,7,8,9 - Hexachlorodibenzofuran (HxCDF)
  1,2,3,4,6,7,8 - Heptachlorodibenzofuran (HpCDF)
  1,2,3,4,7,8,9 - Heptachlorodibenzofuran (HpCDF)
  1,2,3,4,6,7,8,9 - Octachlorodibenzofuran (OCDF)

- Metals

Antimony	Chromium (VI)
Arsenic	Lead
Barium	Nickel
Beryllium	Selenium
Cadmium	Silver
Chromium (III)	Thallium

For most of these constituents, direct and indirect risks were assessed for three different categories of emissions--the 90th percentile baseline, the 50th percentile baseline, and the MACT regulatory alternative emission level. Risks were also assessed for dioxins and mercury for a fourth category of emissions, a more protective regulatory alternative. The four categories of emissions used in calculating direct and indirect risks are as follows:

- Baseline central tendency emissions - 50th percentile emissions determined separately for incinerators, cement kilns, and lightweight aggregate kilns from trial burns and compliance testing

- Baseline high-end emissions - 90th percentile emissions determined separately for incinerators, cement kilns, and lightweight aggregate kilns from trial burns and compliance testing

- MACT floor emissions - proposed MACT standards emissions

- Above the floor emissions - proposed standards more stringent than MACT standards emissions.

d2. Particle Size Distribution

Facility-specific particle size distributions were not used in the analysis. Instead, the particle size distribution was based on the suggested values contained in the Addendum (U.S. EPA, 1993a). The emissions were modeled as unit density (1 g/cm^3) particles in three size classes. The representative median diameters defining the three size classes were 1.0, 6.0, and 15.0 µm. Table II.2 lists the particle size distribution used in the modeling.

Table II.2 Particle Size Distribution and Liquid Scavenging Coefficients

Size Category (µm)	Representative Median Diameter (µm)	Distribution (%)	Liquid and Frozen Scavenging Coefficients (h/mm-s)
< 2	1.0	78	0.4×10^{-4}
2 - 10	6.0	19	4.2×10^{-4}
> 10	15	3	6.7×10^{-4}

For one cement facility, information pertaining to the size distribution of the particles obtained from stack sampling was available. Examination of the size distribution showed that the sizes corresponded to those that might be expected from a cement kiln upstream of the air pollution control device. The conclusion was that the sampling had taken place upstream of the air pollution device or that the device had failed and that the particle size distribution was not representative of that expected from kilns equipped with air pollution control devices.

d3. Scavenging Coefficients

Particulate scavenging coefficients for liquid precipitation and frozen precipitation were obtained from the values provided in Jindal and Heinhold (1991). Liquid and frozen scavenging coefficients were set equal (PEI, 1986). Table II.2 lists the particulate scavenging coefficient for the particle size distribution used in the modeling.

Efforts were undertaken to develop chemical-specific gas scavenging coefficients for the constituents of concern. Due to the limited set of data available, the number of chemicals modeled, and time limitations, chemical-specific gas scavenging coefficients were not used. Instead, gases were assumed to behave as extremely small particles, and a value for the gas scavenging coefficient was taken from Jindal and Heinhold (1991). A vapor-scavenging coefficient of 1.7E-4 (h/mm-s) was used for all cases. Again, liquid and ice gas scavenging coefficients were set equal.

Bidleman in an *Environmental Science & Technology* article (1988), suggests the use of a washout ratio to describe chemical-specific vapor wet deposition for semivolatile compounds (pesticides, PCBs, and PAHs). This washout ratio is equal to the product of the universal gas constant and the temperature, divided by the Henry's law constant. In another *Environmental Science and Technology* article, Eltzer and Hites (1989) reported experimental data on wet deposition of dioxins/furans in Bloomington, Indiana.

In order to apply the washout ratio to the air modeling conducted, the ratio must be converted to a scavenging coefficient. The necessary meteorologic inputs for the conversion are mixing height, temperature, and precipitation rate. Five years of hourly meteorologic data were available for most of the cases modeled. However, adapting the hourly meteorologic data to the development of chemical-specific scavenging coefficients was outside the time constraints of this project. Additionally, with the limitation of only one set of experimental data for dioxin/furan wet vapor deposition, the additional precision gained through the use of chemical-specific gas scavenging coefficients may not be more correct than the simple approximation based on physical properties.

d4. Vapor Dry Deposition to Soils

ISCSTDFT does not calculate the dry deposition of vapors directly. Instead a dry deposition velocity was applied to the vapor air concentration to estimate the vapor flux to the surface. A value of 0.2 cm/s was used for the dry deposition velocity for dioxins. This value was derived from experimental data reported by Koester and Hites (1992) and, in lieu of other data, is considered a reasonable value to use for the deposition of vapors. Appendix C contains the soil concentration equations where the dry deposition velocity is used.

D. Constituents

Three types of constituent groups were modeled in the analysis. Dioxin and furan risks were estimated through the use of the 17 congeners that have toxicity equivalence factors. Direct and indirect risks were estimated for nine different metals and chromium in two oxidation states. The final metal examined was lead. Because no reference dose is available for lead, modeled soil concentrations are compared to a soil level of concern of 400 ppm (U.S. EPA, 1994d). Direct inhalation risks were estimated for hydrogen chloride. Only chronic exposures were modeled for hydrogen chloride because EPA-approved acute health benchmarks were not available.

1. Dioxin Congeners

Each dioxin congener was considered independently in calculating soil, produce, and animal tissue concentrations. The physical and chemical properties for each congener were used in the fate and transport modeling. These congener-specific values are presented in Appendix E with the appropriate references. The basic chemical/physical properties presented in these tables include the following:

- Vapor fraction (f_v)
- Henry's law constant (H)
- Biotransfer factor for beef (B_{beef})
- Biotransfer factor for milk (B_{milk})

- Octanol-water partition coefficient (K_{ow})
- Soil adsorption coefficient (K_{oc})
- Soil-to-plant biotransfer factor (Br)
- Root concentration factor (RCF)
- Air-to-plant biotransfer factor (B_{vpa})
- Fish biota to sediment accumulation factor (BSAF)
- Biotransfer factor for pork (B_{pork})
- Biotransfer factor for chicken (B_{chick})
- Biotransfer factor for eggs (B_{egg})
- Vapor pressure (VP)
- Water solubility (S)
- Molecular weight (MW)
- Diffusivity coefficients in water and air (D_w and D_a).

All other constituent-specific values required by the models have been calculated using these properties.

2. Metals

The physical and chemical properties for each metal were used in the fate and transport modeling. These values are presented in Appendix E with the appropriate references. The basic chemical/physical properties presented in these tables include:

- Soil-to-plant biotransfer factor (Br)
- Fish biota accumulation factor (BAF)
- Fish biota concentration factor (BCF)
- Biotransfer factor for beef (B_{beef})
- Biotransfer factor for milk (B_{milk})
- Biotransfer factor for pork (B_{pork})
- Molecular weight (MW)
- Soil partition coefficients (Kd_s)
- Sediment partition coefficients (Kd_{sw})
- Suspended solids partition coefficients (Kd_{bs})

All other constituent-specific values required by the models have been calculated using these properties.

E. Exposure Pathways and Parameters

1. Overview

The nearest locations for the residents, farmers, and waterbodies were identified for each facility through the telephone survey described previously. All were located with respect to the facility, and the most impacted was selected on the basis of maximum air concentrations and deposition expected due to prevailing wind direction and terrain. Thus, for each facility, the following locations were obtained when available: the most impacted farmers who raised beef cattle, dairy cows, hogs, or chickens for their own consumption; the most impacted watershed;

and the most impacted residence. These locations were used in estimating the direct and indirect exposures due to combustor emissions.

All individuals were assumed to be exposed to combustor emissions through both direct and indirect pathways. For this analysis, direct exposure pathways were defined as direct inhalation only. Indirect exposure via dermal contact with water and soil was not considered. The indirect pathways include ingestion of soil, drinking water, beef, fish, milk, pork, chicken and eggs, aboveground produce (fruits and vegetables), and belowground vegetables. Representative dietary consumption rates of adults and children were obtained from the 1987-88 USDA Nationwide Food Consumption Survey (USDA, 1993) for the consumption of the following food categories: milk, beef, pork, poultry, and vegetables. Consumption rates of freshwater fish for the general population were obtained from 1977-78 USDA Nationwide Food Consumption Survey (USDA, 1978). These consumption rates are mean consumption rates that are representative of the general population. Special subpopulation central tendency freshwater fish ingestion rates were used for the recreational fisher (Murray and Burmaster, 1994, and FIMS, 1993) and the subsistence fisher (Columbia River Inter-Tribal Fish Commission, 1994) to reflect their consumption of the fish they caught.

Also, different dietary items were obtained from different sources (e.g., home gardeners or local grocery stores), depending on the scenario. The source of each diet category represented differing levels of contamination for each facility site. All variations in exposure parameters (i.e., consumption rates, source of food, and level of contamination) were considered for each scenario and pathway. The remainder of this section discusses the exposure pathways of concern in this risk analysis.

2. Contaminated Fraction Analysis

The contaminated fraction is the fraction of the product consumed that is contaminated by emissions from the facility. In any marketplace, some fraction of the goods available will be locally produced and represent the contaminated fraction, with the remaining fraction imported from outside the area of impact of the facility. To arrive at contaminated fraction estimates, a site-specific economic analysis was conducted to determine the percent consumption of locally grown products. The results of this analysis were applied to the portion of each product ingested that was not assumed to be home-produced. These products included milk, poultry, beef, pork, fruits and vegetables, and eggs. The contaminated fractions that were applied in this analysis are presented in Appendix E. In addition to these products, information was collected on locally grown feed grains; however, this information was not used as part of this analysis. Exposures to cattle and poultry via consumption of contaminated grain were low, relative to other exposure pathways and, for this reason, the simplifying assumption was made that the grain was all locally grown. If exposure through this pathway had been relatively high, this information could have been used to further refine exposure estimates. Specifically, this information could have been used to develop site-specific fractions contaminated for the feed grains assumed to be consumed by cattle and poultry.

The economic analysis arrived at an estimate of the fraction of locally produced commodities using the lesser of the farm-level production capacity and the manufacturing/wholesaling capacity of the counties within 50 kilometers of the facilities. Using the *Census of Agriculture, Geographic Series, 1992* (1987 for Louisiana) (U.S. Department of Commerce, 1987a and 1992) the local farm-level production per capita was calculated. The national farm-level production per capita was next calculated. The ratio of the two was used to estimate whether the site was a net importer or exporter. A similar ratio was developed comparing the local per capita manufacturing/wholesaling of each commodity to the national per capita level. The sources of the manufacturing/wholesaling data were *County Business Patterns* (U.S. Department of Commerce, 1992c), the Census of Manufacture (U.S. Department of Commerce, 1987b) and the Census of Wholesale Trade (U.S. Department of Commerce, 1992b). The lesser of the agricultural production ratio and the processing ratio was used as the contaminated fraction. A minimum contaminated fraction value of 0.01 was set as a default.

The type of farmer used to represent the typical farmer was also determined from the economic analysis. The commodity with the highest local production was judged to be most representative of the typical farm type in the area. For urban areas where farm-level production was very low, the typical farmer was assumed to be producing produce only.

The home gardener's home production of produce and the typical farmer's home production of both produce and the one commodity that they were identified as producing was set according to the *Exposure Factors Handbook* (U.S. EPA, 1990a). The remainder of what the home gardener and the typical farmer consumed, and everything that the typical resident consumed, was assumed to be purchased in the local market and contaminated at the fraction arrived at by the economic analysis.

The subsistence scenarios all included at least one pathway for which the fraction contaminated was set at 1. For the subsistence farmer scenarios, both produce and the animal that the farmer was identified as raising were assumed to be home-produced, with a fraction contaminated of 1. The subsistence and recreational fishers' fraction of fish contaminated was also 1. The remainder of the products consumed in these subsistence scenarios was assumed to be purchased in the local market, with the contaminated fraction derived from the economic analysis.

3. Direct Inhalation

Air concentrations of contaminants used in calculating direct inhalation risks were characterized as the summation of vapor air concentration and particle-bound air concentration of contaminants. Individuals were assumed to reside at the location of the maximum air concentration. Other exposure factors required for calculation of direct inhalation risks are presented in Table II.3. All site-specific factors are provided in Appendixes A-1 through A-11.

Table II.3 Exposure Factors for Inhalation of Air

<table>
<tr><th rowspan="2">Parameter</th><th colspan="4">Adult</th><th rowspan="2">Child</th><th rowspan="2">References</th></tr>
<tr><th colspan="2">Residents / Fisher</th><th colspan="2">Farmers</th></tr>
<tr><td>Intake of air</td><td colspan="2">20 m³/d</td><td colspan="2">20 m³/d</td><td>12 m³/d</td><td>Adult: Calculated from values presented in U.S. EPA (1990a)
Child: U.S. EPA (1994e)</td></tr>
<tr><td rowspan="2">Exposure duration</td><td>Central tendency</td><td>High end</td><td>Central tendency</td><td>High end</td><td rowspan="2">6 yr</td><td rowspan="2">Residents/Fisher and Child: U.S. EPA (1990a)
Farmers: Assumption</td></tr>
<tr><td>9 yr</td><td>30 yr</td><td>20 yr</td><td>40 yr</td></tr>
<tr><td>Exposure frequency</td><td colspan="2">350 d/yr</td><td colspan="2">350 d/yr</td><td>350 d/yr</td><td>U.S. EPA (1991)</td></tr>
</table>

The adult breathing rate of 20 m^3/d was derived for a "reference man" using hourly air intake rates for different activity levels. The child inhalation rate was estimated at 12 m^3/d, the value used in the *Mercury Study Report to Congress* (U.S. EPA, 1994e). The *Exposure Factors Handbook* (U.S. EPA, 1990a) suggests that the child inhalation rate is nearly as high as the adult due to increased activity levels. The exposure duration reflects the length of time that an exposed individual resides near the contaminant source. The high-end and central tendency exposure durations, respectively, are intended to represent the 90^{th} and 50^{th} percentiles of time that a person occupies one residence. Because it is assumed that farmers live in one location longer than the general population, a high-end value of 40 years was applied under the farmer scenarios. However, the facility lifetime is 30 years, so, for the remaining 10 years, the farmer is assumed not to breathe contaminated air. A central tendency value of 20 years was assumed and applied for the farmers. An exposure frequency of 350 d/yr was applied to all exposure scenarios. This value accounts for the exposed individuals being in a different uncontaminated environment for a period of 15 d/yr.

4. Direct Soil Ingestion

The soil concentrations of contaminants used in estimating exposure through the direct soil ingestion pathway were characterized as the summation of the particle-bound and vapor phase deposition of contaminants to the soil, less soil losses due to volatilization, leaching, surface runoff, and erosion. The equations for each of the soil loss constants are presented in Appendix C-1.

Soil concentrations may take a number of years to reach steady state or may not reach steady state within the 30-year time period during which the facilities are assumed to operate. As a result, an equation to calculate the average soil concentration over the time period of deposition was derived by integrating the instantaneous soil concentration equation over the time period of deposition. For carcinogens, two forms of the soil-averaging equation were used: one form for when the exposure duration is greater than or equal to the facility operating lifetime, and a second form for when the exposure duration is less than the operating lifetime. For noncarcinogens, a 1-year average soil concentration for the 30th year of the facility operation was used. The soil loss equations are provided in Appendix C-1.

The factors that determine the exposure of individuals to contaminants in soils were the level of contaminant, ingestion rate, exposure duration, and exposure frequency. The level of the contaminant in the soil depended on the location of the individual in relation to the combustion facility. All individuals considered in this assessment were assumed to consume soil found only at their identified locations. All site-specific factors are provided in Appendixes A-1 through A-11. The other exposure factors used in calculating risks from soil ingestion are presented in Table II.4. The ingestion rates applied for the adult and child are based on central tendency values presented in *Exposure Factors Handbook* (U.S. EPA, 1990a). The exposure duration reflects the length of time that an exposed individual resides near the contaminant source. The high-end and central tendency exposure durations, respectively, are intended to represent the 90^{th} and 50^{th} percentiles

of time that a person occupies one residence. A value of 6 years was applied as the exposure duration for a child resident (U.S. EPA, 1990a). A value of 9 years was used as the central tendency exposure duration for all adults modeled under all exposure scenarios (e.g., the adult resident, subsistence fisher, and subsistence farmer). For all adults modeled except for the subsistence farmer, a high-end value of 30 years was applied. Because it is assumed that farmers live in one location longer than the general population, a high-end value of 40 years was applied under this scenario. In addition, a central tendency value of 20 years was estimated and applied. An exposure frequency of 350 d/yr was applied to all exposure scenarios. This value accounts for the exposed individuals being in a different uncontaminated environment for a period of 15 d/yr.

Table II.4 Exposure Factors for Ingestion of Soil

Parameter	Adult				Child	References
	Resident/Fisher		Farmers			
Intake of soil	0.1 g/d		0.1 g/d		0.2 g/d	U.S. EPA (1990a)
Exposure duration	Central tendency	High end	Central tendency	High end	6 yr	Central tendency, high end, and child: U.S. EPA (1990a) Farmers: Assumption
	9 yr	30 yr	20 yr	40 yr		
Exposure frequency	350 d/yr				350 d/yr	U.S. EPA (1991)

5. Aboveground Produce Ingestion Pathway

The indirect exposure due to the ingestion of aboveground produce (fruits and vegetables) depended on the total concentration of contaminants of concern in the leaf and fruit portions of the plant. In this analysis, aboveground produce was classified as protected and unprotected. The produce classified as protected has a protective covering over the edible portion of the produce (e.g., citrus fruit); unprotected produce (e.g., an apple) does not have a protective covering. There are three mechanisms by which produce can be contaminated:

- Root uptake - the root uptake of contaminants available from the soil and their transfer to the aboveground portions of the plant

- Deposition of particles - wet and dry deposition of particle-bound contaminants on the leaves and fruits of plants

- Vapor transfer - the vapor phase uptake of the plants through their foliage.

The total contaminant concentration in aboveground produce is calculated as a sum of contamination occurring through all three of these mechanisms. Because the outer covering on the protected produce acts as a barrier, contamination of this type of produce through deposition of particles and vapor transfer is assumed to be negligible. As a result, contamination of protected produce is assumed to occur only through root uptake. Contamination of unprotected produce is assumed to occur through all three of the above mechanisms.

The methodology used to estimate contamination through vapor transfer takes into consideration the reduction of lipophilic contaminant (i.e., dioxins) concentrations resulting from mechanisms responsible for inhibiting the transfer of the contaminant (i.e., the shape of the produce) and the removal of the contaminants from the edible portion of the produce (e.g., washing, peeling, and cooking). Specifically, the algorithm used to estimate contamination through vapor transfer was developed to estimate the transfer of contaminants into leafy vegetation rather than into bulky aboveground vegetation, such as apples. Because of the shape of bulky produce, transfer of contaminant to the center of the produce is unlikely to occur and, as a result, the inner portions will be largely unimpacted. Additionally, typical removal mechanisms, such as washing, peeling, and cooking, will further reduce residues. Therefore, applying this algorithm to bulk produce would result in overestimating contaminant concentrations. An adjustment factor (VG_{ag}) has been incorporated into the algorithm to address this overestimation for lipophilic compounds (i.e., compounds with a log K_{ow} value greater than 4). In this analysis, VG_{ag} was assigned a value of 0.01 for dioxins for all aboveground fruits and vegetables intended for human consumption. As discussed in the descriptions of the animal ingestion pathways, these same algorithms were applied to forage and silage crops used for animal feed. The compound-specific transfer factors for soil and vapor to aboveground produce are provided in Appendix E.

The factors that determined the exposure of individuals through the ingestion of aboveground produce included the level of contaminant in the vegetable, the fraction of intake that was assumed to be contaminated, the exposure duration, and the exposure frequency. The level of the contaminant in the aboveground produce depended on soil concentration, air concentration, and wet and dry particle deposition at the location where the produce was grown. The aboveground plant concentration was estimated using exposure duration and location-specific deposition rates. Exposure factors that were constant for all exposure scenarios are presented in Table II.5. An ingestion rate of 19.7 g/d (dry weight) was applied for all adults modeled. The child ingestion rate was 14 g/d (dry weight). The USDA survey (1993) is unclear in the division of vegetables between aboveground and belowground vegetables. However, the value used was inferred from the USDA data as used in the *Mercury Study Report to Congress* (U.S. EPA, 1994e). The exposure duration reflects the length of time that an exposed individual resides near the contaminant source. The high-end and central tendency exposure durations, respectively, are intended to represent the 90^{th} and 50^{th} percentiles of time that a person occupies one residence. Because it is assumed that farmers live in one location longer than the general population, a high-end value of 40 years was applied for this scenario. In addition, a central tendency value of 20 years was estimated and applied for the farmer. An exposure frequency of 350 d/yr was applied to all exposure scenarios. This value accounts for the exposed individuals being in a different uncontaminated environment for a period of 15 d/yr. The equations for estimating exposures from the pathway for ingestion of aboveground produce are presented in Appendix C-3.

The fraction of consumption of aboveground produce that was assumed to be contaminated depended on the scenario and the individual facility site. All aboveground produce cultivated by the home gardeners and subsistence farmers was assumed to be contaminated at a higher level due to their proximity to the facility. The subsistence farmers were assumed to eat 100 percent of their vegetables from their own garden. The central tendency home gardener and typical farmer were

Table II.5 Exposure Factors for Ingestion of Aboveground Produce

Parameter	Adult				Child	References
	Residents and Fishers		Farmers			
Intake of above-ground produce	19.7 g/d (dw)		19.7 g/d (dw)		14 g/d (dw)	Adult: U.S. EPA (1990a) and U.S. EPA (1994c) Child: based on U.S. EPA (1994e), USDA (1993)
Exposure duration	Central tendency	High end	Central tendency	High end	6 yr	Residents, fishers, and child: U.S. EPA (1990a) Farmers: Assumption
	9 yr	30 yr	20 yr	40 yr		
Exposure frequency	350 d/yr		350 d/yr		350 d/yr	U.S. EPA (1991)

expected to grow 25 percent of their own produce and to purchase the remaining 75 percent at the local market. In the high-end case, the home gardener and typical farmer were assumed to grow 40 percent of their own produce and to purchase the remaining 60 percent in the local market. All other individuals were assumed to purchase all of their produce at the local market. The percentage of the produce in the local market grown in the contaminated area was estimated on a site-specific basis. All contaminated produce grown by the typical farmer and sold in the local market was assumed to be contaminated with the typical level of contaminants. The fraction of produce from contaminated sources was site-specific, and all site-specific factors are provided in Appendixes A-1 to A-11.

6. Belowground Produce Ingestion Pathway

The contaminant concentrations in belowground vegetables were estimated from the contaminant concentration in the soil in which they were cultivated. The soil-to-root vegetable transfer factors varied for each constituent; Appendix E contains the constituent-specific transfer factors. The methodology used to estimate contamination through root uptake takes into consideration the reduction of lipophilic contaminants (i.e., dioxins) resulting from mechanisms responsible for inhibiting the transfer of the contaminant (i.e., the shape of the produce) and the removal of the contaminants from the edible portion of the produce (e.g., washing, peeling, and cooking). Specifically, the algorithm used to estimate contamination through root uptake was developed to estimate the transfer of contaminants into barley roots rather than into bulky root vegetation, such as carrots. Because of the shape of bulky produce, transfer of the contaminant to the center of the produce is unlikely to occur and the inner portions will be largely unimpacted. Additionally, typical removal mechanisms, such as washing, peeling, and cooking, further reduce residues. Therefore, applying this algorithm to bulk produce would likely overestimate contaminant concentrations. An adjustment factor (VG_{bg}) has been incorporated into the algorithm to address this overestimation for lipophilic compounds (i.e., compounds with a log K_{ow} value greater than 4). In this analysis, VG_{bg} was assigned a value of 0.01 for dioxins for all belowground vegetables intended for human consumption.

The exposure of individuals through the ingestion of belowground vegetables was determined from the level of contaminant in the vegetable, the fraction of intake that was assumed to be contaminated, the exposure duration, and the exposure frequency. The level of the contaminant in the belowground vegetable depended on the soil concentration at the location where the vegetable was cultivated. The exposure factors that were constant for all exposure scenarios are presented in Table II.6. The ingestion rate of 28 g/d (whole weight) for adults and 40 g/d for children (whole weight) is based on central tendency values. The USDA (1993) survey is unclear in the division of vegetables between aboveground and belowground vegetables. However, the value used was inferred from the USDA data as used in the *Mercury Study Report to Congress* (U.S. EPA, 1994e). The consumption rate in whole weight is used with the concentration factor for calculating exposure to dioxins through belowground vegetables. Because there is no root concentration factor for metals, the consumption rate in dry weight is used with soil-to-plant biotransfer factors to calculate exposure to metals through belowground vegetables. A moisture content of 0.87 (calculated from a listing for specific fruits and vegetables) was used in converting vegetables from whole to dry weights (Rice, G., 1994a). The exposure duration reflects the length of time that an exposed individual resides near the contaminant source. The high-end and central tendency exposure durations, respectively, represent the 90^{th} and 50^{th} percentiles of time that a person occupies one residence. Because it is assumed that farmers live in one location longer than the general population, a high-end value of 40 years was applied for this scenario. Additionally, a central tendency value of 20 years was estimated and applied to the farmer scenario. An exposure frequency of 350 d/yr was applied to all exposure scenarios. This value accounts for the exposed individuals being in a different uncontaminated environment for a period of 15 d/yr. The equations for estimating exposures from the belowground vegetable ingestion pathway are provided in Appendix C-3.

The fraction of the consumption of belowground vegetables that was assumed to be contaminated depended upon the scenario and the individual facility site. All belowground vegetables produced by the home gardeners and subsistence farmers were assumed to be contaminated at a higher level due to their proximity to the facility. The subsistence farmers were assumed to eat 100 percent of their vegetables from their own gardens. The central tendency home gardener and typical farmer were expected to grow 25 percent of their own produce and to purchase the remaining 75 percent at the local market. In the high-end case, the home gardener and typical farmer were assumed to grow 40 percent of their own produce and to purchase the remaining 60 percent in the local market. Adult and child residents and the subsistence fisher were assumed to purchase all of their vegetables.

Table II.6 Exposure Factors for Ingestion of Root Vegetables

Parameter	Adult				Child	References
	Residents and Fishers		Farmers			
Intake of belowground vegetables	28 g/d (ww)		28 g/d (ww)		40 g/d (ww)	Adult: U.S. EPA (1990a) and U.S. EPA (1994c) Child: U.S. EPA (1994e), based on USDA (1993)
Exposure duration	Central tendency	High end	Central tendency	High end	6 yr	Residents, fishers, and Child: U.S. EPA (1990a) Farmers: Assumption
	9 yr	30 yr	20 yr	40 yr		
Exposure frequency	350 d/yr		350 d/yr		350 d/yr	U.S. EPA (1991)

The percentage of the product in the local market that was cultivated from the contaminated area was estimated on a site-specific basis. All contaminated produce grown by the typical farmer and sold in the local market was assumed to be contaminated with the typical level of each contaminant. The fraction of belowground vegetables from contaminated sources was site-specific. All site-specific factors applied to this pathway are provided in Appendixes A-1 to A-11.

7. Beef and/or Dairy Ingestion Pathway

The contaminant concentrations in beef tissue and milk products were estimated based on the amount of contaminant that the cattle were assumed to have consumed through their diet. The cattle's diet was assumed to consist of forage (i.e., pasture grass and hay), silage, and grain. Additional contamination of the cattle occurred through the ingestion of soil. In this analysis, it was assumed that each item consumed originated from the site, therefore 100 percent contamination was assumed.

The amount of grain, silage, forage, and soil consumed was assumed to vary between dairy and beef cattle. Consumption of these items was also assumed to vary between cattle raised by subsistence and typical farmers. The diet of the subsistence beef cattle is comprised mainly of pasture grasses, hay, and silage. Soil consumption is relatively high resulting from the time at pasture. The diet of the typical beef cattle was supplemented with an increased amount of grain because these cattle were permitted only limited grazing. The limited grazing also limited the typical beef cattle's exposure to contaminated soil. Total consumption rates for typical beef cattle are lower because they are slaughtered younger and lighter. Unlike beef cattle, the subsistence and typical dairy cattle were assumed to be the same weight. However, dairy cattle raised by typical farmers were assumed to be confined so that their grazing was infrequent. As a result, the diet of these dairy cattle was supplemented with an increased amount of grain. The limited grazing for the typical dairy cattle also limited their exposure to contaminated soil. (Rice, 1994b)

The total contaminant concentration in the feed items (i.e., forage, silage, and grain) is calculated as a sum of contamination occurring through the following mechanisms:

- Root uptake - root uptake of contaminants available from the soil and their transfer to the aboveground portions of the plant
- Deposition of particles - wet and dry deposition of particle-bound contaminants on plants
- Vapor transfer - the vapor phase uptake of the plants through their foliage.

As discussed previously, vegetation can be classified as protected and unprotected (i.e., not having a protective outer covering). In this analysis, grain is classified as protected feed. Because the outer covering on the protected feed acts as a barrier, contamination of this type of feed product through deposition of particles and vapor transfer is assumed to be negligible. As a result, contamination of grain was assumed to occur only through root uptake. Contamination of forage and silage, unprotected vegetation, was assumed to occur through all three of the above mechanisms.

The methodology used to estimate contamination through vapor transfer takes into consideration the reduction of lipophilic contaminant (i.e., dioxins) concentrations resulting from mechanisms responsible for inhibiting the transfer of the contaminant. Specifically, the algorithm used to estimate contamination through vapor transfer was developed to estimate the transfer of contaminants into leafy vegetation rather than into bulky aboveground vegetation, such as silage. Because of the shape of bulky aboveground vegetation, transfer of contaminant to the center is unlikely to occur, and, as a result, the inner portions will be largely unimpacted. Therefore, applying this algorithm to bulk silage would result in overestimating contaminant concentrations. An adjustment factor (VG_{ag}) has been incorporated into the algorithm to address this overestimation for lipophilic compounds (i.e., compounds with a log K_{ow} value greater than 4). In this analysis, Vg_{ag} was assigned a value of 0.5 for dioxins for all silage.

The factors used to determine the exposure of individuals to contaminants in beef and dairy products included the level of contaminant in the beef or milk product, the fraction of intake that is assumed to be contaminated, exposure duration, and exposure frequency. The level of contaminant in the beef or dairy product depended on the location of the site of the beef or dairy farm and the source of the animals' diet. Other exposure factors are presented in Table II.7. Adult and child consumption rates for meat obtained from beef cattle and milk products obtained from dairy cattle were obtained from the USDA Nationwide Food Consumption Survey (USDA, 1993). Whole weight consumption rates were used for dioxins and all of the metals except cadmium and selenium. For these metals, dry weight consumption rates were calculated using moisture contents of 0.6 for beef and 0.9 for milk (Lorber, 1995). The exposure duration reflects the length of time that an exposed individual resides near the contaminant source. The high-end and central tendency exposure durations, respectively, represent the 90th and 50th percentiles of time that a person occupies one residence. Because it is assumed that farmers live in one location longer than the general population, a high-end value of 40 years was applied for this scenario. In addition, a central tendency value of 20 years was estimated and applied for the farmer. An exposure frequency of 350 d/yr was applied to all exposure scenarios. This value accounts for the exposed individuals being in a different uncontaminated environment for a period of 15 d/yr.

Table II.7 Exposure Factors for Beef and Milk Products

Parameter	Beef Cattle				Dairy Cows				References
Length of exposure to deposition									
forage	0.12 yr				0.12 yr				U.S. EPA (1990b)
silage	0.16 yr				0.16 yr				
Consumption rate	Subsistence Farmer		Typical Farmer		Subsistence Farmer		Typical Farmer		
forage	8.8 kg/d (dw)		3.8 kg/d (dw)		13.2 kg/d (dw)		6.2 kg/d (dw)		Boone et al. (1981); and Rice (1994b)
grain	0.47 kg/d (dw)		3.8 kg/d (dw)		3.0 kg/d (dw)		12.2 kg/d (dw)		Boone et al. (1981); and Rice (1994b)
silage	2.5 kg/d (dw)		1.0 kg/d (dw)		4.1 kg/d (dw)		1.9 kg/d (dw)		Boone et al. (1981); and Rice (1994b)
soil	0.5 kg/d		0.25 kg/d		0.4 kg/d		0..2 kg/d		NAS (1987); and Rice (1994 a and b)
Adult consumption rate	57 g/d				181 g/d				USDA (1993)
Exposure duration of adult	Resident and fishers		Farmers		Resident and fishers		Farmers		Resident and fishers: U.S. EPA (1990a) Farmers: Assumption
	Central tendency	High end	Central tendency	High end	Central tendency	High end	Central tendency	High end	
	9 yr	30 yr	20 yr	40 yr	9 yr	30 yr	20 yr	40 yr	
Child consumption rate	32 g/d				353 g/d				USDA (1993)
Exposure duration of child	6 yr				6 yr				U.S. EPA (1990a)

The factors listed in Table II.7 and the fraction of the diet that was assumed to be contaminated at this level is dependent upon the individual exposure scenario evaluated and the individual sites. The contaminated fractions are site-specific and are presented in Appendixes A-1 to A-11.

8. Poultry Meat and Egg Ingestion Pathways

The poultry and egg ingestion pathways were considered only for exposures to dioxins and furans. The chickens considered in the subsistence poultry farm scenario were assumed to be free- range animals. The chickens considered in all other scenarios were considered to be raised on commercial poultry farms. All poultry was exposed to combustion emissions through their diet.

In the subsistence poultry farmer analysis, the free-range chickens' contamination route was through the ingestion of soil. Ten percent of their ingestion rate was assumed to be contaminated soil. Ten percent was selected for use in the analysis to be consistent with the study from which the biotransfer factors were obtained. The grain that the subsistence poultry farmers' free-range chickens consume is assumed to be free of contamination. The soil concentrations were estimated using the soil equations described in Appendix C-1.

Chickens raised on commercial poultry farms were assumed to consume contaminated grain but were not in contact with any contaminated soil. Because it was assumed that the grain was home grown, the fraction contaminant for the grain was 1. The grain contaminant concentration was estimated using the aboveground vegetation algorithm presented in Appendix C-3. Through the use of this algorithm, the total contaminant concentration in the aboveground vegetation is calculated as a sum of contamination occurring through root uptake, deposition of particles, and vapor transfer. However, because grain was classified as a protected vegetation in this analysis, contamination of grain through deposition of particles and vapor transfer was assumed to be negligible. As a result, contamination of grain was assumed to occur only through root uptake. The dioxin and furans ingested by chickens were partitioned into concentrations in thigh meat and eggs. The partitioning was dependent upon compound-specific biotransfer factors for poultry and eggs, which are provided in Appendix E. The equations for estimating exposures from the egg and poultry meat ingestion pathways are presented in Appendix C-3.

The factors that determined the exposure of individuals to contaminants in poultry thigh meat and eggs included the level of contaminant in the poultry meat and eggs, the fraction of intake that was assumed to be contaminated, exposure duration, and exposure frequency. The level of the contaminant in the poultry meat or eggs depended on the location of the site of the poultry farm. All site-specific factors are provided in Appendixes A-1 through A-11. Other exposure factors are presented in Table II.8. Adult and child consumption rates for meat obtained from poultry and eggs were obtained from the Nationwide Food Consumption Survey (USDA, 1993). The exposure duration reflects the length of time that an exposed individual resides near the contaminant source. The high-end and central tendency exposure durations, respectively, represent the 90th and 50th percentiles of time that a person occupies one residence. Because it is assumed that farmers live in one location longer than the general population, a high-end value of 40 years was applied for this scenario. An exposure frequency of 350 d/yr was applied to all exposure scenarios. This value accounts for the exposed individuals being in a different uncontaminated environment for a period of 15 d/yr.

Table II.8 Exposure Factors for Poultry and Egg Products

<table>
<tr><th rowspan="2">Parameter</th><th colspan="4">Adult</th><th rowspan="2">Child</th><th rowspan="2">References</th></tr>
<tr><th colspan="2">Residents and Fishers</th><th colspan="2">Farmers</th></tr>
<tr><td>Sub. farmer - free-range chickens: fraction of diet that is soil</td><td colspan="2">0.1</td><td colspan="2">0.1</td><td>0.1</td><td>Stephens et al. (1992)</td></tr>
<tr><td>Ingestion rate of chicken thigh meat</td><td colspan="2">34 g/d</td><td colspan="2">34 g/d</td><td>17 g/d</td><td>USDA (1993)</td></tr>
<tr><td>Ingestion rate of eggs</td><td colspan="2">23 g/d</td><td colspan="2">23 g/d</td><td>11 g/d</td><td>USDA (1993)</td></tr>
<tr><td rowspan="2">Exposure duration</td><td>Central tendency</td><td>High end</td><td>Central tendency</td><td>High end</td><td rowspan="2">6 yr</td><td rowspan="2">Residents and fishers: U.S. EPA (1990a)
Farmers: Assumption</td></tr>
<tr><td>9 yr</td><td>30 yr</td><td>20 yr</td><td>40 yr</td></tr>
<tr><td>Exposure frequency</td><td colspan="2">350 d/yr</td><td colspan="2">350 d/yr</td><td>350d/yr</td><td>U.S. EPA (1991)</td></tr>
</table>

9. Pork Ingestion Pathway

The hogs in this analysis were assumed to be free-range animals. Their diet consisted of silage, grain, and associated soil. Because the silage, grain, and soil were assumed to have been obtained from the site under evaluation, the fraction contaminant assigned to each was assumed to be 1. The silage and grain contaminant concentrations were estimated using the aboveground vegetation algorithm presented in Appendix C-3. Through the use of this algorithm, the total contaminant concentration in the aboveground vegetation is calculated as a sum of contamination occurring through root uptake, deposition of particles, and vapor transfer. However, because grain was classified as protected vegetation in this analysis, contamination of this feed item through deposition of particles and vapor transfer was assumed to be negligible. As a result, contamination of grain was assumed to occur only through root uptake.

The methodology used to estimate contamination through vapor transfer takes into consideration the reduction of lipophilic contaminant (i.e., dioxins) concentrations resulting from mechanisms responsible for inhibiting the transfer of the contaminant. Specifically, the algorithm used to estimate contamination through vapor transfer was developed to estimate the transfer of contaminants into leafy vegetation rather than into bulky aboveground vegetation, such as silage. Because of the shape of bulky aboveground vegetation, transfer of contaminant to the center is unlikely to occur, and as a result, the inner portions will be largely unimpacted. Therefore, applying this algorithm to bulk silage would result in overestimating contaminant concentrations. An adjustment factor (VG_{ag}) has been incorporated into the algorithm to address this overestimation for lipophilic compounds (i.e., compounds with a log K_{ow} value greater than 4). In this analysis, Vg_{ag} was assigned a value of 0.5 for dioxins for all silage.

Biotransfer factors for pork were only readily available for cadmium and selenium. In the absence of reported biotransfer factors for pork for the remaining chemicals of concern, beef biotransfer factors were applied. An alternative approach to applying beef biotransfer factors would be to estimate pork biotransfer factors based on milk biotransfer factors. As discussed in the dioxin document (U.S. EPA, 1994c), milk biotransfer factors can be converted to beef biotransfer factors by assuming fat contents of beef and milk. This same methodology could be applied by assuming fat content for pork. However, the uncertainty associated with both methodologies (i.e., applying beef biotransfer factors to pork and estimating pork biotransfer factors based on fat contents of milk and pork) cannot be evaluated at this time due to insufficient data on biotransfer in pork. The equations for the pork ingestion pathway are provided in Appendix C-3.

The factors that determined the exposure of individuals to contaminants in pork products included the level of contaminant in the pork, the fraction of intake that is assumed to be contaminated, exposure duration, and exposure frequency. The level of the contaminant in the pork product depended on the location of the hog farm and the source of the animals' diet. These factors and the fraction of the diet that was assumed to be contaminated at this level depended on the individual exposure scenario evaluated. Other exposure factors are presented in Table II.9. Site-specific factors are provided in Appendixes A-1 through A-11.

Table II.9 Exposure Factors for Pork Products

<table>
<tr><th>Parameter</th><th colspan="4">Pork</th><th>References</th></tr>
<tr><td>Consumption of grain</td><td colspan="4">3 kg/d (dw)</td><td>U.S.EPA (1990b)</td></tr>
<tr><td>Consumption rate for silage</td><td colspan="4">1.3 kg/d (dw)</td><td>U.S. EPA (1990b)</td></tr>
<tr><td>Consumption rate of soil</td><td colspan="4">0.37 kg/d</td><td>U.S. EPA (1993a)</td></tr>
<tr><td>Adult pork consumption</td><td colspan="4">17 g/d</td><td>USDA (1993)</td></tr>
<tr><td rowspan="3">Exposure duration - adult</td><td colspan="2">Residents and Fishers</td><td colspan="2">Farmers</td><td rowspan="2"></td></tr>
<tr><td>Central tendency</td><td>High end</td><td>Central tendency</td><td>High end</td></tr>
<tr><td>9 yr</td><td>30 yr</td><td>20 yr</td><td>40 yr</td><td>Resident and fishers: U.S. EPA (1990a); high-end Farmers: Assumption</td></tr>
<tr><td>Child pork consumption</td><td colspan="4">9 g/d</td><td>USDA (1993)</td></tr>
<tr><td>Exposure duration - child</td><td colspan="4">6 yr</td><td>U.S.EPA (1990a)</td></tr>
<tr><td>Exposure frequency</td><td colspan="4">350 d/yr</td><td>U.S.EPA (1991)</td></tr>
</table>

10. Fish Ingestion Pathway

Fish were assumed to be exposed to combustion emissions through the water column in the waterbodies near combustors. Five pathways result in contaminant loading of the water column: (1) direct deposition; (2) runoff from impervious surfaces from within the watershed; (3) runoff from pervious surfaces from within the watershed; (4) soil erosion from the total watershed; and (5) direct diffusion of vapor phase contaminant into the surface water. Other pathways have been omitted or their contributions were assumed to be negligible in comparison with the pathways being evaluated. For example, soil erosion losses for residential areas and agricultural fields located within a watershed were considered to be inconsequential because contaminated soil from these areas due to erosion would be matched by an equal amount of contaminated soil eroding onto these areas.

The universal soil loss equation (USLE) together with a sediment delivery ratio are used to estimate the rate of soil erosion from the watershed. The surface water concentration algorithms include a sediment mass balance so that sediments are buried and assumed to be lost from the waterbody to the extent that soil erosion exceeds the loss of suspended solids due to downstream outflows. Therefore, sediments do not accumulate in the waterbody over time and an equilibrium relationship is maintained between the surficial layer of sediments and the water column. The USLE
values and other parameter values that were used for the watershed and waterbody are presented in Table II.10. All site-specific factors are provided in Appendixes A-1 through A-11.

Table II.10 Waterbody and Watershed Parameters Used to Determine Surface Water Contamination

Parameter	Value	References
USLE soil erodibility factor	0.36 ton/acre	Droppo et al. (1989)
USLE length-slope factor	1.5	U.S.EPA (1988)
USLE cover management factor	0.1	U.S.EPA (1993a)
USLE supporting practice factor	1	U.S.EPA (1993a)
Soil enrichment ratio	3 for organics 1 for metals	U.S.EPA (1993a)
Total suspended solids in water column	10	U.S.EPA (1993a)
Waterbody temperature	298 K	Assumption; equals 25 °C
Gas phase transfer coefficient	946,080 m/yr	Estimated using gas phase transfer coefficient equation
Depth of benthic upper layer	0.03 m	Based on center of range given in U.S. EPA (1993a)

The contaminants in the water column consist of dissolved constituents and constituents associated with suspended solids. For metals, the dissolved fraction is more significant. The equations used to estimate surface water concentrations are presented in Appendix C-2. The results of these equations are used to estimate the concentration of contaminants in fish. The concentrations in fish tissue are estimated using compound-specific bioconcentration factors (BCFs) or sediment bioaccumulation factors (BSAFs). Due to the limited availability of BSAFs, these factors were applied only for dioxins in this analysis. The BCFs and BSAFs used in this analysis are presented in Appendix E. The equations used to estimate exposures from the ingestion of freshwater fish are presented in Appendix C-3.

The factors that determine the exposure of individuals to contaminants in fish products include: the level of contaminant in the fish, the fraction of intake that is assumed to be contaminated, exposure duration, and exposure frequency. The level of the contaminant in the fish is dependent on the location of the waterbody and the contamination in the water column. These factors were discussed in the description of the drinking water pathway. These factors and the fraction of the diet that is assumed to be contaminated at this level are dependent upon the individual exposure scenario evaluated. All site-specific factors are provided in Appendixes A-1 through A-11. The other exposure factors that are constant for all exposure scenarios are presented in Table II.11.

Table II.11 Exposure Factors for Ingestion of Freshwater Fish

Parameter	Fish		References
Fish lipid content	0.07		U.S. EPA (1994c)
Adult resident and farmer fish consumption rate	1.64 g/d		U.S. EPA (1992)
Adult recreational fisher consumption rate	30 g/d		Murray and Burmaster (1994); FIMS (1993)
Adult subsistence fisher consumption rate	60 g/d		Columbia River (1994)
Exposure duration - adult	Central tendency	High end	
Residents and fishers Farmers	9 yr 20 yr	30 yr 40 yr	U.S. EPA (1990a) Assumption
Child fish consumption rate	0.35 g/d		Scaled adult value based on body weight
Exposure duration - child	6 yr		U.S. EPA (1990a)
Exposure frequency	350 d/yr		U.S. EPA (1991)

11. Drinking Water

Surface water concentrations of constituents of concern were calculated for three or four waterbodies for each representative facility. Drinking water risks were calculated only for those surface waterbodies that were identified as drinking water sources. Five pathways result in contaminant loading of the water column: (1) direct deposition; (2) runoff from impervious surfaces from within the watershed; (3) runoff from pervious surfaces from within the watershed; (4) soil erosion from the total watershed; and (5) direct diffusion of vapor phase contaminant into the surface water. Other pathways have been omitted or their contributions were assumed to be negligible in comparison with the pathways being evaluated. For example, soil erosion losses for residential areas and agricultural fields located within a watershed were considered to be inconsequential because contaminated soil from these areas due to erosion would be matched by an equal amount of contaminated soil eroding onto these areas.

The USLE and a sediment delivery ratio are used to estimate the rate of soil erosion from the watershed. The surface water concentration algorithms include a sediment mass balance so that sediments are buried and assumed to be lost from the waterbody to the extent that soil erosion exceeds the loss of suspended solids due to downstream outflows. Therefore, sediments do not accumulate in the waterbody over time and an equilibrium relationship is maintained between the surficial layer of sediments and the water column. The USLE values and other parameter values that were used for the watershed and waterbody are presented in Table II.11. All site-specific factors are found in Appendixes A-1 through A-11.

The total concentration of constituents was partitioned between the sediment and the water column. Risks from drinking water ingestion were calculated from the concentrations of constituents dissolved in the water column for each waterbody identified as a drinking water source. The constituent concentration that was dissolved in the water column differed from the total water column concentration. The total water column concentration was the summation of the constituent dissolved in the water and the constituent associated with suspended solids. Partitioning between water and sediment varied with the constituent. For metals, the dissolved fraction was more important, and, for dioxins, the suspended solids fraction was more significant. The equations for determining surface water concentrations are provided in Appendix C-2.

The factors that determined the exposure of individuals to contaminants in drinking water included the level of contamination, ingestion rate, exposure duration, and exposure frequency. The level of the contaminant in the drinking water was dependent on the location and size of the waterbody and its associated watershed. This pathway was evaluated only for those sites in which a surface waterbody was identified as a source of drinking water. The exposure factors that are common to all sites are presented in Table II.12. An ingestion rate of 1.4 L/d was applied for the adults based on central tendency values. The child ingestion rate was estiamted at 0.5 L/d. The exposure duration reflects the length of time that an exposed individual resides near the contaminant source. The high-end and central tendency exposure durations, respectively, represent the 90^{th} and 50^{th} percentiles of time that a person occupies one residence. Because it is assumed that farmers live in one location longer than the general population, a high-end value of 40 years was applied for this scenario. An exposure frequency of 350 d/yr was applied to all exposure scenarios.

Table II.12 Exposure Factors for Ingestion of Drinking Water

<table>
<tr><th rowspan="2">Parameter</th><th colspan="4">Adult</th><th rowspan="2">Child</th><th rowspan="2">Ref.</th></tr>
<tr><th colspan="2">Residents and Fishers</th><th colspan="2">Farmers</th></tr>
<tr><td>Intake of drinking water</td><td colspan="2">1.4 L/d</td><td colspan="2">1.4 L/d</td><td>0.5 L/d</td><td>Adult: U.S. EPA (1994c)
Child: U.S. EPA (1994e)</td></tr>
<tr><td rowspan="2">Exposure duration</td><td>Central tendency</td><td>High end</td><td>Central tendency</td><td>High end</td><td rowspan="2">6 yr</td><td rowspan="2">Residents, Fisher and child: U.S. EPA (1990a)
Farmers: Assumption</td></tr>
<tr><td>9 yr</td><td>30 yr</td><td>20 yr</td><td>40 yr</td></tr>
<tr><td>Exposure frequency</td><td colspan="2">350 d/yr</td><td colspan="2">350 d/yr</td><td>350 d/yr</td><td>U.S. EPA (1991)</td></tr>
</table>

12. Breast Milk Ingestion

Under each scenario, infants' 2,3,7,8-TCDD-TEQ exposure through the consumption of breast milk was estimated for infants nursed by the adult exposure population groups in this analysis. Exposures were compared to background exposure levels because there is not an accepted dose and thus risks could not be calculated. Exposures over and above background levels are of concern because it is thought that adverse impacts on developmental biology may be occurring in humans at or within an order of magnitude of current average background exposures (U.S. EPA, 1994b). Infants that are breastfed are expected to be among the most highly exposed and most susceptible human populations. Those exposure factors that are common to all sites are presented in Table II.13. All site-specific factors are provided in Appendixes A-1 through A-11.

Table II.13 Breast Milk Exposure Factors

Parameter	Exposure Factor	
	Parameter Values	References
Body weight of infant	10 kg	U.S. EPA, 1994b
Exposure duration for infant	1 yr	U.S. EPA, 1994b
Ingestion rate of breast milk	0.80 g/d	U.S. EPA, 1994b
Body weight of mother	70 kg	Adult body weight: U.S. EPA, 1990a
Fraction of mother's weight that is fat	0.3	U.S. EPA, 1994b
Fraction of dioxin that is absorbed	0.90	U.S. EPA, 1994b
Fraction of absorbed dioxin that is stored in fat	0.90	U.S. EPA, 1994b
Fraction of fat in breast milk	0.04	U.S. EPA, 1994b

The exposure of the infant through the consumption of contaminated breast milk was estimated based on the mother's exposure (assumed to be at steady state over her period of exposure) and then was compared to infant exposure levels that would result if the mother were exposed to background levels of 2,3,7,8-TCDD. For each scenario, the result was a ratio of the infant dose from the mother's site-specific exposure to the average infant dose from a mother exposed to TEQ at typical background levels. The average background infant dose calculated for comparison was 50 pg/kg/day of 2,3,7,8-TCDD-TEQ, based on a measured U.S. background level of 16 ppt of TEQ in the lipid portion of the breastmilk (U.S. EPA, 1994b). The methodology used to calculate the intake of TEQ through breast milk is summarized in Appendix C-4.